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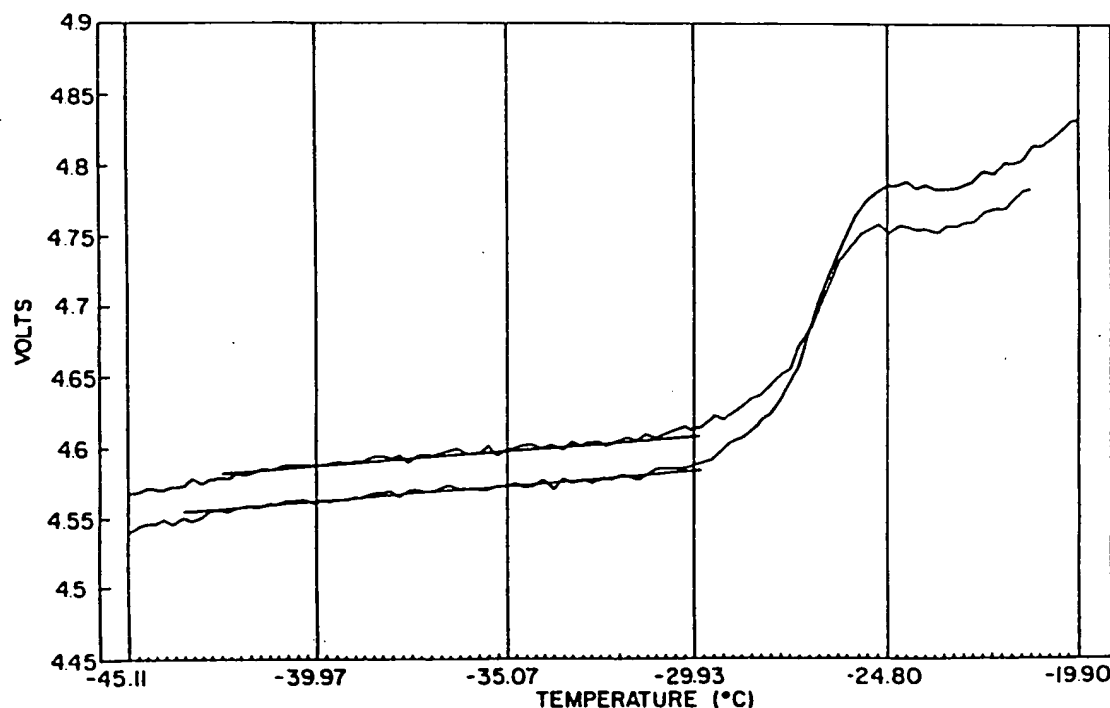
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(54) Title: METHOD OF FREEZING CELLS AND CELL-LIKE MATERIALS



(57) Abstract

A process is provided for freezing, including freeze-drying of cells, cell-membranes or cell-like materials using a cryoprotectant medium which stabilizes the cells or membranes for freezing or freeze-drying and allows for freezing or freeze-drying to be performed at -60 °C or higher.

METHOD OF FREEZING CELLS AND  
CELL-LIKE MATERIALS

FIELD OF THE INVENTION

The present invention is directed to a method for  
5 freezing, including freeze-drying, cells or cell-like  
materials. In particular, the invention is directed  
to a method for freezing platelets for storage.

BACKGROUND OF THE INVENTION

Current storage of fresh human platelets in liquid  
10 form (i.e., as platelet-rich concentrate in residual  
plasma) is limited in the following ways:

1) Platelets in liquid suspension (platelet  
concentrate) are generally not stored refrigerated as  
they suffer from a well-documented "storage lesion"  
15 involving loss of clotting function and in vivo  
viability (refer to AABB Technical Manual, 10th  
edition, 1990, pp.51-52). Platelet concentrates  
stored refrigerated are limited to a 72 hour shelf  
life due to the rapidity of the storage decay. The  
20 method used by most blood banks is to store platelet  
concentrate at room temperature (20-24 deg. C) with  
continuous agitation by mechanical rocking.  
Agitation is essential at these temperatures to  
prevent cell aggregate formation. Currently

regulations of the U.S. Food and Drug Administration (FDA) limit room temperature storage to 5 days.

2) The quality of room temperature stored platelet concentrates, as measured by aggregometry and other in vitro measures, decays after the first 24 hours of storage to some 75-85% of fresh values. Further deterioration occurs by five days of storage, such that the therapeutic value is only about 30% of fresh cells (i.e., the clotting efficacy of infused 5 day-old concentrate in patients, as measured by their bleeding time reduction, is only some 30% of a comparable dose of fresh platelets).

3) FDA limits room temperature storage of platelet concentrates to five days due to the threat of bacterial growth in the nutrient rich plasma concentrate. Contamination of platelet concentrates by Yersinia bacteria has been associated with deaths due to platelet transfusion.

4) The short shelf life means that some 25% of platelet concentrates collected by U.S. blood banks become unusable by outdating. This is a loss of a valuable voluntary resource.

The current useful method of storage of platelet concentrates in frozen form uses a 5% DMSO storage method developed by Schiffer et al (1983) Annals N.Y. Acad. Sci. 411, 161-169. This requires that the cells be stored at - 120 deg. C in the vapor phase of liquid nitrogen. Most blood banks do not use this method due to the expense of liquid nitrogen storage, plus the impracticality of shipping in liquid nitrogen. (See AABB Technical Manual, 1990, pp. 100-101 for review of blood cell freezing literature). Valeri has reported a 6% DMSO method that allows

storage at temperatures as high as -65 deg. C,  
(referenced in the AABB Manual p. 102), a temperature  
compatible with ultra-low mechanical freezers. These  
freezers are also very expensive and have limited  
5 storage capacity.

An accepted shelf life for frozen platelets  
in 5% DMSO is 3 years. In actual clinical use, a  
frozen-thawed DMSO unit of platelets will normally  
exhibit about 50-60% of the clotting efficacy seen  
10 with a fresh platelet concentrate unit (i.e., usually  
two units of frozen thawed platelets are needed to  
achieve the same effect in vivo as one fresh unit).

It should be noted that FDA has not approved any  
DMSO platelet frozen storage method due to  
15 controversy over the efficacy and possible toxicity  
of DMSO (usually the frozen cells are thawed and  
infused directly, along with the 5% DMSO). Thus,  
U.S. blood banks today only freeze and infuse  
platelets with the approval of their medical review  
20 boards (i.e., interstate transport is prohibited).

Platelets are collected at most blood collection  
facilities, ranging from large regional blood centers  
(over 100,000 donations per year) to local hospital  
blood banks. Platelets can only be stored for 5 days  
25 as a platelet-rich plasma fraction at room  
temperature according to current FDA regulations.  
Although platelets can be frozen at -80 degrees for  
up to two years, the expense of freezing has  
discouraged frozen storage among civilian entities.  
30 The short shelf life is a major impediment to  
directed pre-deposit of plateletpheresis units.

A second issue problem is the transport of frozen  
platelets, which presents difficulties in container

design, especially for air shipment. There is thus a need for lyophilized platelets which can be stored, shipped and reconstituted for therapeutic use.

Platelets play a vital role in blood clot formation and platelet transfusions are administered to arrest an existing bleeding condition or to prevent an imminent loss of blood. Often platelet transfusions are indicated when the patient cannot mobilize his own platelet reserves, as a result of standard chemotherapy treatments or diseases that cause low levels of circulating platelets or loss of normal platelet function. The American Red Cross (ARC) in 1987 reported a total of 4,500,000 transfusions of random donor platelet units and 350,000 transfusions of plateletpheresis units during calendar year 1986 in the United States. Some 245,000 patients received platelet transfusions during this period. The average patient receiving random donor units isolated from whole blood donations required 6 platelet units per transfusion event and also required 6 separate transfusions per year. The high rate of transfusions reflects the need for multiple transfusions for cancer patients undergoing aggressive chemotherapy or bone marrow transplantation as an adjunct to chemotherapy.

Multiple platelet transfusions can cause immune sensitization and rejection, especially when random donor units are used. This sensitization reaction, combined with improved plateletpheresis methods, has spurred demand for directed-donor plateletpheresis units. Plateletpheresis selectively isolates platelets from whole blood and returns the depleted blood to the donor's arm. This allows collection of concentrated platelet units from a single donor, as often as once per week. Each plateletpheresis unit

contains the equivalent of 5-6 units obtained from donated whole blood (random donor units). Plateletpheresis allows more closely matched donors, such as close relatives, to donate and minimize the risk of sensitization. The use of concentrated plateletpheresis units also reduces the patient's exposure to numerous random donors, which reduces both sensitization risk and exposure to viral contaminants (a chemotherapy patient may require 60 platelet units during the course of treatment, and may be exposed to over 50 random donors).

Platelets are prescribed to control massive bleeding events before or during cardiopulmonary bypass surgery, and organ transplants. Unlike red cells, the normal human body possesses platelet reserves that can be mobilized rapidly if blood is lost. As a result, the U.S. Department of Health and Human Services advises that platelets not be wasted on prophylactic transfusions for routine surgery or even most trauma situations (patients can cope with a major bleed of 20 units by mobilizing platelets provided red blood cells are administered).

Bone marrow transplants designed to restore marrow destroyed by chemotherapy accounts for the single most intensive use of platelet transfusions. Most patients recovering from chemotherapy require at least three weeks (and sometimes months) before the new bone marrow graft can begin to produce platelets. During this period circulating platelet levels are maintained by transfusions, which must be frequent due to the short 5 day circulation lifetime of normal platelets.

The present invention provides a method utilizing a buffer for platelets which allows frozen storage at

high temperatures (i.e., in the range of -20 deg. C). This temperature range is easily achieved by conventional mechanical freezers such as chest freezers now used for food storage. The present invention enables long term frozen storage, which will obviate the short shelf life of room temperature or refrigerated storage, as well as the threat of bacterial growth in room temperature stored liquid concentrates. The prohibitive costs of liquid nitrogen frozen storage or ultra-low temperature mechanical freezers are also eliminated, and the use of DMSO is eliminated.

The present invention provides a method for freezing (and freeze-drying) cells or cell-like materials, including platelets, by the use of polymer glass transition theory to determine an effective cryopreservation for natural cells suspended in an aqueous environment. As reviewed by Levine and Slade (1987) Water Science Reviews (F. Franks, ed.) Vol. 3, pp. 79-185, Cambridge University Press, in aqueous systems comprising many natural and synthetic polymers, water acts as a plasticizer that affects the glass-to-rubber transition temperatures ( $T_g'$ ) of the aqueous-polymer system. This area of research has had a significant impact on the design of polymeric food materials (such as those based on starches), since the raising or lowering of  $T_g'$  can confer unique advantages for processing or storage stability of a material.

A working definition of a glass (Levine and Slade, 1987) is that it comprises a mechanical solid capable of resisting flow. In a typical amorphous glass the viscosity is extremely high, in the range of  $10^{11}$  to  $10^{14}$  Pa-s at the glass transition temperature ( $T_g$ ). The  $T_g$  value, as illustrated in Figure 2.4 of Slade

and Levine (1987) occurs at the transition from the glassy fluid to the rubbery fluid state for systems comprising glassy or partially crystalline polymers. Below  $T_g$ , in the glass phase, the high viscosities  
5 preclude molecular diffusion and hence chemical reactions (which can lead to product spoilage) cannot proceed at significant rates. From this same figure another important point can be seen: that once the product temperature exceeds  $T_g$ , viscous flow can  
10 occur in the rubbery state, allowing for molecular diffusion and chemical reaction rates to proceed with exponential kinetics (WLF kinetics).

As a practical example, this explains why certain frozen and perishable biological products, such as  
15 human blood cells, must be stored within carefully defined temperature ranges (American Association of Blood Banks Technical Manual, 10th edition, 1990, chapter 5, pp. 91-103). Currently accepted blood cell freezing solutions containing glycerol or  
20 dimethylsulfoxide (DMSO) form glasses at very low temperatures (between  $-65^{\circ}\text{C}$  and  $-198^{\circ}\text{C}$ ), thereby maintaining the cells in a chemically unreactive environment. However, exposure to temperatures that exceed  $T_g$  lead to poor cell viability as measured by  
25 red blood cell circulation time following freeze-thawing and transfusion or bleeding time reduction following transfusion of frozen-thawed platelets. In essence, the perishable cells can spoil even at temperatures below  $0^{\circ}\text{C}$  normally thought of as  
30 "freezing temperatures" because the cryoprotective media have  $T_g$  values much lower than the  $-20^{\circ}\text{C}$  range commonly achieved by standard kitchen freezers.

Many of the fundamental principles of glass transition theory have derived from physical chemical  
35 studies in single component systems (see Levine and



Slade, 1987) capable of forming a homogeneous "pure" glassy phase at the glass transition temperature ( $T_g$ ) characteristic of that component, and in multicomponent systems. The present invention, however, provides multi-component aqueous cryopreservative systems that at appropriate temperatures form partially crystalline mixtures of water ice with interspersed regions of a separate amorphous glass phase. As defined in Pikal (1990), BioPharm, Sop-Oct 1990, the glass transition temperature of the amorphous phase in a partially crystalline aqueous system will be defined as  $T_g'$ , to distinguish this particular phase from the glass transition temperatures of individual buffer components (i.e., the component  $T_g$  values).

#### SUMMARY OF THE INVENTION

The present invention provides a method, and cryoprotective compositions for use therewith, for freezing, including freeze-drying, cells or cell-like materials. The cells and cell-like materials include erythrocytes, platelets, cell-membranes, stem cells, lymphocytes, and the like. The invention provides cryoprotective compositions which protect the cells or cell-like materials during freezing, freeze-drying and/or storage and which permit these processes and storage to be performed at temperatures which do not require liquid nitrogen, potentially toxic materials such as DMSO, or expensive low temperature refrigeration equipment. Typically, according to the present invention, freezing or freeze-drying may be performed above about  $-45^{\circ}\text{C}$  to about room temperature, and storage conditions may be from  $-80^{\circ}\text{C}$  to  $0^{\circ}\text{C}$  (for frozen cells or cell-like materials), or up to room temperature (for lyophilized cells or cell-like materials). Predetermined temperatures for freezing, freeze-drying and storage of the cells

which allow for optimum cell characteristics or recovery and shelf-life may be obtained by utilization of cryoprotective compositions according to the invention.

5 The aqueous mixture of cells, cell membrane or cell-like materials will be characterized by a high glass transition temperature, usually above about -60°C, and will contain a cryoprotective component. This component will comprise one or more permeants,  
10 i.e., compounds capable of penetrating the cells or cell membranes. The cryoprotective components will also contain one or more impermeants, i.e., compounds impermeable to the cells or cell membranes, wherein the amount of impermeants present in the mixture is a  
15 weight fraction sufficient to overcome the predicted depression in the glass transition temperature of the mixture attributable to the permeants.

#### BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 is a phase diagram of an aqueous-polymer  
20 solution.

FIG. 2 is the profile of a DSC thermal analysis of a buffer described in Example 1.

FIG. 3 is an osmoscan profile for rehydrated red cells described in Example 6.

25 FIG. 4 is a plot to glass transition temperature as a function of drying time of a buffered red blood cell mixture described in Example 3.

FIG. 5 is a plot of glass transition temperature as a function of residual moisture of a buffered red  
30 blood cell mixture described in Example 3.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

Among the polymeric food ingredients that have been studied by others are natural polymers such as gelatin, gluten, starches, and frozen aqueous  
35 solutions of small sugars (i.e., mono- and

disaccharides), polyols (glycerol), and starch hydrolysis products. Synthetic polymers such as PVP (polyvinylpyrrolidone) and PVAc (polyvinylacetate) in water have also been studied. Each of these materials in aqueous solution can be considered as an amorphous or partially crystalline polymer system that is plasticized by water. Glass transition theory as applied to these partially crystalline water-polymer systems focuses on the critical variables of moisture content (or percent dryness), temperature, and time to predict and regulate the cryostabilization of frozen or freeze dried products. The present invention provides aqueous-polymer buffers for the cryostabilization of natural cells by application of these principles.

Referring to Figure 1 an idealized phase diagram is shown for an aqueous-polymer solution comprising an amorphous, partially crystalline system, which illustrates the relationship between the moisture content (or percent solids) and temperature. The hypothetical system is characterized by distinct freezing and glass transition ( $T_g'$ ) curves that define different physical states: R = rubbery phase, SOL = solution phase, ICE/SOL = mixture of ice and solution, and G = glassy phase. The essential principle is that when the system is maintained at temperatures below the glass transition curve, an amorphous (noncrystalline) glass exists that is characterized by extremely high viscosities that prevent molecular diffusion on practical time scales. Thus, in the glassy state most chemical reactions such as degradative oxidation reactions that can damage cellular components, are inhibited. The slow kinetics of chemical reactions under these conditions lead to a cryostabilized product at the appropriate temperatures.

From Figure 1 it can also be seen that  $T_g'$  increases most rapidly in aqueous glassy polymer systems of low moisture content. This is also expressed as a depression of  $T_g'$  by the plasticizing effect of increasing water content. PVP represents a typical water-soluble, glassy (non-crystallizable) polymer. Therefore, reduction of water content (i.e., by freeze-drying) is one approach to elevated temperature storage stability, as the resulting dried polymer composition has a higher glass transition temperature. It can be seen from our hypothetical curve in Figure 1 for a water-PVP system, that the  $T_g'$  can exceed 0 degrees Celsius at sufficiently low moisture content. This indicates that prolonged storage at above freezing temperatures can be achieved under the proper conditions.

It is known that  $T_g$  for a pure polymer varies with the polymer weight average molecular weight:  $T_g$  increases with increasing average molecular weight, up to a limiting molecular weight value. The greatest increase in glass transition temperature is seen at low moisture contents (i.e., high weight percent of polymer). Thus, selection of water-soluble polymers of increasing average molecular weight to incorporate into an aqueous cryostabilizing buffer can further elevate the  $T_g'$  of the amorphous phase, due to the increased  $T_g$  of the individual polymer component. The relative contribution of each polymer component to the overall  $T_g'$  increases as the weight percent of that component in the aqueous solution increases.

Furthermore, by increasing the weight fraction of starch, or conversely increasing the weight fraction of water will respectively increase or depress the  $T_g'$  of the system. It can thus be extrapolated that

more refined control of the  $T_g'$  value for a particular aqueous cryostabilizing buffer system can be attained by adding to pure water (which has a  $T_g$  of  $-135^\circ\text{C}$ ) multiple solute components of differing  
5 molecular weights (and hence higher or lower component  $T_g$  values) in appropriate weight percentages.

According to the invention these considerations of individual component  $T_g$  values and the weight percent  
10 of each component in an aqueous are utilized to provide multicomponent buffer formulations that have elevated (above  $-45^\circ\text{C}$ )  $T_g'$  values. The calculated buffer  $T_g'$  values, based on known component  $T_g$  values and their weight percent in a particular buffer  
15 formulation, allow accurate predictions of the buffer  $T_g'$ .

For freeze-drying a cryostabilizing buffer must have a  $T_g'$  that is appreciably above  $-45^\circ\text{C}$ , since the product cannot be kept frozen at lower temperatures  
20 if efficient sublimation is to occur. Below this temperature the vapor pressure of water is so low that even under high vacuums of 100 mTorr or less achieved in conventional freeze-drying equipment the rate of sublimation is too low to be practical.

25 The phenomenon of freeze concentration during the freezing process is another consideration. In aqueous systems containing dissolved solutes, the initial freezing event involves conversion of liquid water to crystalline ice. The dissolved solutes are  
30 thereby concentrated out of the ice phase into a residual liquid phase in which the concentration of dissolved solutes increases significantly. At sufficiently low temperatures, below  $T_g'$ , this non-crystalline phase becomes a glass. Implicit in this

description is the fact that valuable components such as proteins or blood cells also become concentrated into the glassy phase. The high electrolyte and buffer concentrations in this phase can be damaging to proteins or cellular membranes. Hence, it is preferable to start with the minimal acceptable concentrations of salts and buffering agents (buffered phosphate), as these will become further concentrated during freezing into the same amorphous phase that contains the product of interest.

The process of lyophilization by sublimation is defined as removal of water vapor directly from the ice phase. During lyophilization the ice crystals are removed by sublimation, leaving open pores or channels in the frozen, partly dried matrix. Formation of these channels is critical for thorough primary drying (in which the bulk of the water is removed as water vapor from the ice phase), as these channels allow water vapor to escape from regions below the surface of the product "cake". During primary drying the product should be maintained below the collapse temperature, which is usually identical to the  $T_g'$  of the amorphous glass phase containing regions of maximally concentrated solutes. If the product temperature exceeds  $T_g'$  during primary drying, then regions of amorphous glass will have sufficient fluidity to undergo viscous flow once the ice is sublimed, thereby blocking the open channels and preventing further sublimation. Thus, it can be seen that cryostabilizing buffers must first achieve a measurable and elevated  $T_g'$  value that will allow the material to be held below  $T_g'$  during ice sublimation.

Once the bulk of the water in the product is removed during primary drying, the secondary drying

phyase begins. During secondary drying, the residual moisture in the amorphous phase is removed by evaporative or vacuum drying. Evaporative drying involves removal of water vapor from the nonicy  
5 state.

The accepted methods for frozen storage of human blood cells (red cells, platelets, stem cells and lymphocytes) generally involve aqueous glycerol or DMSO solutions. Both of these compounds have very  
10 low glass transition temperatures ( $T_g$  values), such that the current formulations for cell freezing (40% w/v glycerol or 5% v/v DMSO; see the AABB Technical Manual, 1990) have low glass transition temperatures that are below about  $-65^{\circ}\text{C}$  (in these systems the  
15 aqueous solution is referred to as having a  $T_g$  value, since the term  $T_g'$  is meant to specify glass transition temperature in a partially crystalline system). In addition, both glycerol and DMSO are potent chaotropic agents that prevent the formation  
20 of crystalline ice in aqueous solutions when present in the amounts currently used. Although this prevents ice crystal damage to cells during frozen storage at ultralow temperatures, the requirement of ice channel formation during freeze-drying suggests  
25 that these cryoprotectant formulations are not useful for freeze-drying by sublimation, or for freeze-evaporative drying because of the need for very low frozen temperatures at which the vapor pressure of water is very low. This also explains the empirical  
30 findings reviewed in the AABB Technical Manual (1990), chapter 5, that cells stored frozen in either of these solutions lose their functional viability if the storage temperature exceeds  $-65^{\circ}\text{C}$  for the high glycerol solution, or  $-120^{\circ}\text{C}$  for the DMSO solution:  
35 frozen storage at temperatures that exceed  $T_g$  lead to a glass-to-rubber transition in which viscous flow

occurs in the rubbery state, allowing for molecular diffusion and degradative chemical reactions to proceed at appreciable rates. Neither the existing 40% glycerol system or the DMSO system are useful for high temperature frozen storage (in the range of -20°C), but this temperature range is a necessity for efficient lyophilization.

The present invention provides aqueous buffer solutions for cryostabilization of cells and cell-like materials that comprise buffers having elevated glass transition temperatures ( $T_g'$ ). The higher the glass transition temperature for a particular aqueous suspension of biological cells in a buffered polymer mixture, the higher the useful storage temperature. From Figure 1 it can be seen that the glass transition curve for any aqueous polymer system depends upon the weight fraction of total solids in the solution. Based on the foregoing discussion, the following considerations should be used in the selection of an aqueous cryostabilizing buffer system according to the invention for maintaining perishable biological materials, such as cells or proteins, in a stable frozen state (either for frozen storage or during a freeze-drying procedure):

- 1) The buffer should have the highest practical glass transition curve ( $T_g'$ ), with a minimal component of salts or buffering agents that may contribute to freeze-concentrate damage.
- 2) The overall glass transition temperature of a particular aqueous buffer system will depend on the glass transition temperatures of each of the individual solutes and upon their respective weight fraction in the mixture. This relationship can be approximated by the following:



Equation 1.

$$Tg'(\text{buffer}) = (TgA)(Wt.\%A) + (TgB) \dots + (Wt.\%B) + (TgN) \\ (Wt.\%N) - 5.2 \text{ } ^\circ\text{C}$$

5        where  $Tg'(\text{buffer})$  is the glass transition  
temperature of the total solution;  $Tg A$  is  
the glass transition temperature of solute A;  
Wt. % A is the weight fraction percent of  
solute A in the buffer; N is the last member  
of N components; and  
10        5.2  $^\circ\text{C}$  is an empirically derived value to  
correct for volume displacement of the solid  
components in the solution.

3)        For use with biological or artificial  
membrane systems (i.e., cells or liposomes), the  
15        buffer should contain permeant cryoprotectant agents  
capable of penetrating the phospholipid bilayer of  
the membrane to stabilize the internal lipid bilayer,  
and also to stabilize intracellular or intravesicle  
components (organelles, internal membranes, enzymes,  
20        etc.). Useful membrane-permeants include small  
sugars; such as monosaccharides, and polyalcohols  
(polyols) such as glycerol or polypropylene glycol.  
These small sugars and polyols generally have low  
individual glass transition temperatures, and their  
25        inclusion in a buffering system will lower the  
overall  $Tg'$  of the solution proportional to their  
weight fraction in the solution, as described in  
Equation 1 above. These same polyhydroxy compounds  
also serve as water replacement agents as suggested  
30        by Crowe (Bio Chem. Biophys. Acta, 939, 327-334  
(1988)), to produce the structure of cell components,  
such as the phospholipid bilayer.

- 4) To achieve elevated glass transition temperatures for aqueous buffers comprising membrane permeant small sugars and/or polyols, one or more water soluble polymers must be included in sufficient weight fraction percentages to overcome the Tg-depression caused by the cell permeant components. Use of higher average molecular weight polymers is helpful as Tg for an amorphous polymer increases with molecular weight. These high molecular weight polymers can comprise natural (starches, gelatins, etc. derived from plant, animal or microbial sources) or synthetic (PVP) polymers, or mixtures of polymers of various average molecular weights.
- 5) For use in transfusion medicine, the components of the aqueous buffer system must also be biocompatible, nontoxic, and available as sterile, pyrogen-free materials.

Using Equation 1 above, buffers are provided based on the calculated glass transition temperature, as shown, for example, in Table 1. Equation 1 shows that control over the Tg' of an aqueous cryostabilizing buffer system can be achieved by exploiting the glass transition temperature characteristic of each individual buffer component and its weight fraction in the buffer solution.

Preferred impermeant compounds include amorphous and/or partially crystalline polymers or mixtures thereof. These may be natural or synthetic polymers, preferably of molecular weight over about 300, and most preferably about 10,000-500,000. The polymers are preferably present in the solution in weight percentages from about 1% to their limit of solubility. Preferred weight fractions are 5%-25%.

Preferred permeant compounds include carbohydrates, preferably monosaccharides, disaccharides or mixtures thereof. Typically each of the permeants will be present in a weight fraction  
5 from about 0.01% to their respective solubility limits. Preferred weight fractions are from about 0.5% to 20%.

The preferred monosaccharides are 6-carbon hexose sugars and 5-carbon pentose sugars. Preferred  
10 disaccharides are maltose, lactose, sucrose, trehalose.

Polyalcohols may also be used as permeants, preferably in concentrations of 0.1% to 40% by volume, and most preferably in the range of 5%-25%.

15 In Table I below, the reported glass transition temperatures for a series of useful buffer components are shown. These values are reported in Slade and Levine (1987), pp. 112-115.

Table I.

## REPORTED GLASS TRANSITION TEMPERATURE VALUES.

5	<u>Starch Hydrolysis Products</u>	<u>Manufacturer</u>	<u>Tg' (deg. C)</u>
	Paselli MD- 10 (potato)	AVEBE	-8
	Paselli SA- 10 (potato)	AVEBE	-9.5
	Maltrin M150 (corn)	GPC	-13.5
10	<u>Polyalcohols</u>	<u>Molec. Wt.</u>	<u>Tg' (deg. C)</u>
	ethylene glycol	62.1	-85
	1,3-butanediol	90.1	-63.5
15	glycerol	92.1	-65@
20	<u>Sugars (Mono/Di saccharides)</u>	<u>Molec. Wt.</u>	<u>Tg' (deg. C)</u>
	xylose	150.1	-48
	ribose	150.1	-47
	glucose	180.2	-43
	fructose	180.2	-42
	galactose	180.2	-41.5
	mannose	180.2	-41
	sucrose	342.3	-32
	maltose	342.3	-29.5
	trehalose	342.3	-29.5
25	lactose	342.3	-28

	<u>Polymers</u>	<u>Approx. Average MW</u>	<u>Tg' (deg. C) *</u>
	PEG	300	-63.5
5	gelatin	N.D.	-8
	dextran	9,400	-13.5
	hydroxyethyl starch (HES)	N.D.	-6.5 <sup>(1)</sup>
	PVP-10	10,000	-26
	PVP-40	40,000	-20.5
10	PEG = polyethylene glycol PVP = polyvinylpyrrolidone		

Pure water has an estimated Tg of - 135°C.

\* The reported polymer Tg values in Slade and Levine (1987), p. 131, are compiled from literature values (the value for gelatin is based on collapse temperature during freeze-drying).

(1) No average molecular weight value is reported in Slade and Levine for HES, and this value will vary depending on the average MW (HES is available in a range of molecular weights, up to about 500,000).  
 @ Pure glycerol has a Tg of -95°C.

From the representative Tg' values presented in Table I, it and the teachings herein on these kinds of components, added in different weight fraction proportions, can be used to control the final Tg' of an aqueous buffered medium. Use of multicomponent buffers containing low molecular weight, membrane permeable molecules (polyalcohols and monosaccharides) are vital for preservation of intracellular structures. As seen from Table I, these small molecules have low individual Tg' values, and if present in large concentrations would lead to excessively low buffer Tg' values (i.e., the accepted 40% glycerol medium for freezing red cells has a low glass transition due to the -65°C glass transition of the glycerol component). Thus, these small molecules should preferably be used in low concentrations if a high Tg' buffer is desired. In addition, these small

molecules can be formulated in combination with one or more polymers of varying average molecular weights to raise the overall  $T_g'$  of the buffer. By these strategies a suitable cellular cryostabilizing buffer  
5 for use under a range of freezing temperatures (and ambient temperatures in the freeze-drying process) can be formulated.

Other buffer parameters, such as potential cell toxicity, cell aggregation behavior, or cellular  
10 cryostabilizing efficacy, under the desired freezing or freeze-drying conditions may also be considered in selecting components of the buffer. Different buffer components may be required for specific mammalian cell types; for example, in the present invention we  
15 show that glycerol is amenable to human red blood cell cryopreservation, but is not as efficacious with human platelets. Hence the method of the present invention focuses buffer design in terms of the physical-chemical requirements of freezing or freeze-  
20 drying, but each mammalian or other cell type may have special requirements based on its unique differentiated properties (i.e., the need to preserve oxyhemoglobin in mature red blood cells or the need to preserve nuclear structures in nucleated cells).

25 The calculated buffer  $T_g'$  value can be directly compared to the measured value determined by thermal analysis by differential scanning calorimetry (DSC) analysis. A representative DSC profile for one aqueous buffer formulation is shown in Figure 2, for  
30 a three component buffer containing as its principle weight fraction components 5% mannose/10% lactose/20% PVP-40,000 MW (trace buffer salts are present but are ignored for the purpose of calculating  $T_g'$  as their contribution is minimal). The calculated  $T_g'$   
35 derived from Equation 1 for this formulation is -

30.7°C, and in Figure 2 the DSC traces for two sample runs show the measured values to be -30.0°C and -30.25°C. These values are in excellent agreement with the calculated Tg' value. It should be noted  
5 that in practice this cryostabilizing buffer was diluted in the ratio 2.3 parts buffer: 1 part cell suspension, so in Figure 2 the DSC analysis was performed on a 2.3:1 mixture of buffer:water to approximate final concentrations in actual use.

10 It will be understood that the buffers according to the present invention may also contain basic salts compatible with the biological material. Such salts include electrolytes, capacitors, metal cations, metabolites, buffer salts, vitamins, hormones, growth  
15 factors, and the like. The cells, cell-membranes and cell-like materials which may be treated according to the present invention include mamalian cells (including human), tieeues, peripheral blood cells (red blood cells, platelets, stem cells, leucocytes),  
20 mammalian cell membranes, including membranes of periferal blood cells.

From the foregoing description one of ordinary skill in the art may formulate cryostabilizing buffers for use in frozen storage or for use in  
25 freeze-drying of perishable biological cells or proteins.

### Examples

#### Example 1

For frozen storage stability, we formulated several  
30 three component buffers listed in Table 2, following the main requirements: 1) the buffer must include at least one membrane permeant cryoprotectant, selected

from available monosaccharides that can traverse phospholipid bilayers (polyacohols may also be used); 2) the buffer may include a membrane impermeant cryoprotectant, usually a disaccharide or higher molecular weight carbohydrate or polymer; 3) at least one polymer must be present in sufficient weight percentage and having sufficiently high average molecular weight (hence high Tg) to boost the glass transition temperature (Tg') of the buffer solution; and 4) the relative weight percentages of the individual buffer solutes must be adjusted so that the calculated Tg' exceeds -45°C, and preferably for convenient frozen storage, is above -25°C (buffers prepared to have a calculated Tg' are then measured by DSC analysis to confirm the actual Tg' at final buffer concentrations contemplated for use with cell suspensions); 5) the use of polyhydroxy components (monosaccharides, disaccharides, polyalcohols, starches) contributes to membrane stabililization by water replacement.

In Figure 2 we show a typical DSC thermal analysis profile obtained from a sample of buffer #1(5% mannose/10% lactose/20% PVP-40) in Table 2. The buffer:water mixture exhibits a characteristic and reproducible inflection point at the Tg' onset temperature. By use of DSC analysis, the calculated Tg' for any known aqueous buffer formulation may be confirmed. In addition, DSC analysis can be used to uniquely identify and characterize a buffer formulation in terms of its measured Tg'. This same kind of analysis can also be applied to mixtures of buffer and biological cells.

#### Example 2



In Table 3 we predict the  $T_g'$  of a multicomponent mixture. By varying the individual components along the theme of monosaccharide/disaccharide/polymer, buffers are formulated with actual  $T_g'$  values measured by DSC analysis that correspond closely to the calculated value. Furthermore, by varying the individual component weight fractions in the solution (expressed as a w/v percent), and selecting polymers of desired average molecular weight, it is possible to design buffers that have a range of  $T_g'$  values within the useful temperature limits of  $-45^{\circ}\text{C}$  to  $0^{\circ}\text{C}$ . It should be noted that the measured  $T_g'$  values in Table 3 are for 2.3:1 dilutions of buffer: water to mimic mixing the buffer with an aqueous suspension of cells. Furthermore, in a freeze-drying application (where water is removed from the system by either sublimation or evaporation), the starting  $T_g'$  will increase as the moisture content is reduced. Thus, although these buffers all have starting  $T_g'$  values in the range of  $-33.5^{\circ}\text{C}$  to  $-21.25^{\circ}\text{C}$ , the final dried product will have a  $T_g'$  considerably above these measured starting values. It is the final  $T_g'$  of the dried product that will determine the storage temperature limit for the dry material.

### 25 Example 3

In Figure 1 we described a hypothetical aqueous, partially crystalline system to illustrate the prediction from glass transition theory that the glass transition temperature of the amorphous phase ( $T_g'$ ) should rise as residual moisture decreases (or as % solids increases). From Figure 1 it can also be expected that the rise in  $T_g'$  is most rapid at low residual moisture levels (i.e., at about 10% residual moisture or less). In this example we demonstrate the practice of this concept with an aqueous

suspension of human red blood cells and a mixture of cryoprotectants, which is first frozen and then lyophilized to reduce the moisture content.

Packed human red blood cells were mixed in a 1 :  
5 1.6 ratio by volume (1 part cells : 1.6 parts buffer)  
with a cryostabilizing aqueous buffer comprising the  
following components:

1.7 M glucose  
15% (w/v) hydroxyethyl starch, 500,000 MW<sub>av</sub>  
10 3% (w/v) polyvinylpyrrolidone, 360,000 MW<sub>av</sub>  
Basic Buffer Salts (see Table 1).

The resulting mixture of red blood cells and  
cryoprotective buffers was analyzed by differential  
scanning calorimetry, and the onset of the Tg'  
15 transition for this mixture was observed to occur at  
about -38°C. The red blood cell and buffer mixture  
was then spread in thin layers in several Petri  
dishes and frozen at -40°C on the shelf of a Virtis  
lyophilizer (thin films were prepared to minimize  
20 temperature gradients that might form within thicker  
samples). After complete freezing, the samples were  
lyophilized at a constant shelf temperature of -38°C  
and pressure of 75 mTorr. At various time points  
separate samples were removed and weighed to  
25 determine the percent weight loss, from which it is  
possible to estimate the residual moisture content  
(the solids used to prepare the buffer are  
nonvolatile, so weight loss directly reflects the  
extent of removal of water vapor). The partially  
30 dried samples were also analyzed by differential  
scanning calorimetry to determine their glass  
transition temperature.

The results are shown in Figures 4-5. As expected, the sample Tg' increased with longer drying times, in a linear relationship (Figure 4). The drying cycle was stopped in this study after about 180 hours, at which time the sample glass transition temperature had risen to between +2°C to +7°C. In Figure 5 our parallel weight loss measurements show that this rise in sample Tg' follows the loss of water vapor, as predicted by glass transition theory. As expected from the example in Figure 1, we observed a change in the rate of Tg' increase when the sample reached about 11% residual moisture (i.e., the slope of the curve changes). This confirmed our expectations that an incremental reduction in residual moisture at low moisture contents leads to a larger increase in the sample Tg'. Thus we expect that the residual moisture content of mixtures of biological cells and cryostablizing compounds can be used to determine the product storage temperature and shelf life. The greatest advantage for ambient temperature storage will likely occur at low residual moisture content (i.e., at about 10% residual moisture or less).

This example illustrates the application of glass transition temperature theory to preservation of biological cells.

#### Example 4

Several of the buffer formulations listed in Tables 1-3 were used as cryoprotectants with fresh human red blood cells. Refrigerated packed red blood cells isolated from whole human blood collected in standard citrate-based anticoagulant were obtained from a blood bank. The cells were washed in dextrose-saline to remove the storage solution, and then 5 ml of washed red cells were mixed with 5.7 ml of each

buffer (all concentrations in Tables 1-3 are for the manufactured buffers, prior to mixing with cells). An additional 5.75 ml of each buffer was then added, with additional mixing. The buffer/red cell mixtures  
5 were then frozen rapidly in a -80°C ethanol bath, and the frozen samples stored 24 hours at either -80°C or -38°C. Frozen samples were thawed in a 40°C water bath with agitation, and washed in a series of reconstitution buffers designed to return the cells  
10 to isotonic conditions with minimal osmotic shock, and to remove any lysed cell debris. The thawed and washed cell suspensions were then subjected to analysis.

The post-thaw reconstitution procedure was  
15 performed on each sample as follows:

1) Thawed red cells were removed from the 40°C water bath and 10 ml of 37°C reconstitution buffer (2000 mOsmol) was added. After addition of the first  
10 ml, another 10 ml of 2000 mOsmol buffer was added  
20 to the cells. The reconstitution buffers used in this procedure are based on a basic 300 mOsmol buffer recipe:

19% (w/v) PVP-10,000 MW  
5 mM ATP  
25 1.47 mM monobasic potassium phosphate  
8.1 mM dibasic sodium phosphate  
adjusted to pH 7.2

The above basic 300 mOsmol recipe was adjusted to either 2000 mOsmol or 1400 mOsmol by addition of  
30 potassium phosphate.

2) After mixing-in the 2000 mOsmol buffer, the cells were further diluted by sequentially adding two 10 ml

aliquots of a 1400 mOsmol reconstitution buffer  
(prepared according to the basic recipe above).

3) At this step a 200 microliter sample of cells is  
removed for measurement of cellular hemoglobin  
5 recovery (this data is presented in Tables 4-6 as the  
Cell Recovery at Reconstitution).

4) The remaining red cell suspension is centrifuged  
at 1500 xg for 5 minutes, and the supernatant  
discarded. The cell pellet is then suspended in  
10 10 ml 1400 mOsmol buffer, and then another 10 ml of  
1400 mOsmol buffer is added. This suspension is  
further diluted with two serial 10 ml aliquots of the  
basic 300 mOsmol buffer listed above, and the cells  
are again centrifuged and the supernatant discarded.

15 5) The final cell pellet is then suspended in two  
serial aliquots of the basic 300 mOsmol buffer  
containing PVP-10,000 MW. To this suspension two  
serial 10 ml aliquots of the following buffer are  
added to complete the osmotic step-down of the cells  
20 to isotonic conditions:

10% (w/v) PVP-2500 MW  
213 mM NaCl  
5 mM dibasic sodium phosphate  
5% glucose  
25 pH 7.2 and 300 mOsmol

The remaining analyses shown in Tables 4-6 are  
performed on this final cell suspension.

The following in vitro parameters were measured for  
each sample:

- 1) Cell recovery at reconstitution (step 3 of the reconstitution protocol), measured by the recovery of cellular hemoglobin using a spectrophotometric assay.
- 2) Overall cell recovery after reconstitution of the cells in 300 mOsmol PVP-2,500 MW buffer, again measured by hemoglobin retention in the final cell pellet.
- 3) Osmotic stability of recovered cells in physiological saline (weakened cells lyse upon incubation in saline, and the released hemoglobin can be measured in the supernatant).
- 4) Red cell indices: Mean Corpuscular Volume (MCV), Mean Corpuscular Hemoglobin (MCH), and Mean Corpuscular Hemoglobin Concentration (MCHC) are obtained from a Serono-Baker hematology analyzer.
- 5) The recovery of functional hemoglobin is measured spectrophotometrically, and expressed as the percent of oxyhemoglobin, methemoglobin, and hemichromes present in the sample.
- 6) Red cell deformability (Dlmax) is measured by ektacytometry, which measures the extent of cell elasticity when subjected to a viscous shear stress. The Dlmax expresses the maximum deformability, and can be expressed as a percent of the control Dlmax observed with fresh red cells.
- 7) An osmoscan profile is obtained by combining the ektacytometry with a continuous osmotic solution gradient, to evaluate deformability under hypertonic and hypotonic conditions.

8) The Relative Filtration Index (RFI) measures the ability of cells to traverse a filter containing a 5 micron pore size (normal human red cells are about 2x5 microns in size). This mechanical barrier  
5 simulates circulatory stress encountered in the microvasculature.

9) Cell density is measured to assess the degree of cell swelling.

In Tables 4-6 we show the data obtained from  
10 freeze-thaw experiments in which human red cells were frozen and then stored at either -80°C or -38°C for 24 hours, and then thawed, reconstituted to isotonic conditions, and analyzed. The cryoprotectant buffers #1-9 are the same as those listed in Table 2.  
15 Duplicate cell samples (n=2) were evaluated for each buffer, and the mean values are reported in Tables 4-6. In each Table we also show the expected values obtained from fresh red cell samples analyzed as controls.

20 From the data in Tables 4-6 it can be seen that all of the freezing buffers tested confer significant cryostability to human red blood cells frozen and stored at -80°C, as measured by the percent of intact cells recovered at reconstitution. This protection  
25 extends to initial cell recoveries for those samples stored as high as -38°C in the same buffer formulations. This result is consistent with the elevated calculated Tg' values (see Table 2) for these buffers. In addition, we noted that the PVP  
30 polymer based buffers in Table 2 offered the advantage that very little cell aggregation occurred after thawing, in contrast to some of the buffer formulations reported in Table 1 that use different polymer species (for example, fructose-dextran

buffers were associated with cell aggregation, while fructose-PVP buffers exhibited no cell aggregation). Thus, although PVP and dextran can be used to elevate  $T_g'$ , PVP is preferred since red cell aggregation is  
5 not observed after freeze-thawing in the presence of PVP.

The cryostabilizing properties of the buffers tested in Tables 4-6 at elevated temperatures of  $-38^\circ\text{C}$  suggest that high temperature frozen storage of  
10 human red cells can be achieved. In Tables 4-6 we observed that in general the reconstituted red cells showed reduced cell deformability and filterability (the  $D_{\text{max}}$  and RFI values, respectively). In addition, elevated hemichrome levels were observed,  
15 as though some hemoglobin oxidation had occurred. These observations suggested that a further refinement of the cell permeant (i.e., the monosaccharide component) of these buffers might lead to improved cellular cryostability at elevated frozen  
20 temperatures. In the next example we added a highly membrane permeable polyalcohol, glycerol, to our buffer formulations.

#### Example 5

The history of human red cell cryopreservation has  
25 focused on the use of either high glycerol alone (40% w/v solution), requiring frozen storage at  $-80^\circ\text{C}$ , or use of low glycerol (20% w/v solution), requiring frozen storage at  $-120^\circ\text{C}$  in the vapor phase of liquid nitrogen. These very low storage temperatures are  
30 dictated by the low glass transition temperatures of aqueous glycerol solutions. From the principles of buffer design outlined herein, we have formulated low glycerol buffers containing carbohydrates and polymers that act as impermeant cryoprotectants that



also elevate the Tg' to a temperature range above -45°C.

In Tables 7-9 we demonstrate the effect of using multicomponent buffers containing glycerol or  
5 propanediol as a highly permeant cryoprotectant, in combination with small sugars and various polymers. In these experiments human red blood cells were mixed in a 1:3 volume ratio (cells:buffer) with a particular buffer formulation, and then frozen and  
10 stored at elevated freezing temperature (between -20° and -25°C). About 5 ml of fresh starting packed red cells were used. The frozen cells were thawed and reconstituted by a series of dilutions to return them to isotonic conditions, according to the following  
15 protocol:

1) To the thawed cells two 5 ml aliquots of 2000 mOsmol reconstitution buffer (from Example 1) is added and mixed-in with the cells. This is followed by two 5 ml aliquots of 1400 mOsmol reconstitution  
20 buffer (Example 1) to yield a diluted cell suspension.

2) The diluted cells are recovered by centrifugation and the supernatant is discarded. The cell pellet is suspended in 5 ml 1400 mOsmol buffer, then diluted  
25 with another 3 ml of 1400 mOsmol buffer, then diluted again with two 5 ml aliquots of a 300 mOsmol dextrose-saline buffer (5% dextrose/0.9 % NaCl, w/v, adjusted to 300 mOsmol). At this point a 200 microliter sample is removed for the initial  
30 measurement of cell recovery, as in Example 1.

3) The cells are again pelleted by centrifugation and the supernatant discarded. The cells are suspended in 5 ml commercial dextrose-saline (Baxter

Fenwal), and diluted with an additional 3 ml of commercial dextrose-saline. This final cell suspension is used for the remaining analyses in Tables 7-9.

5     The cell parameters measured in Tables 7-9 are as described in Example 1. In Table 7 we show the results of freezing red cells at high temperature (-22°C) in a series of buffers containing 25% v/v glycerol in the initial buffer formulation (the  
10   starting buffer is diluted in the ratio of 1 volume packed red cells: 3 volumes buffer), so the final concentrations of buffer components in the frozen cell suspension is reduced. These conditions are also used in the experiments outlined in Tables 8 and  
15   9.

In Tables 7-9 a significant improvement in the cell deformability (DImax), osmoscan trace relative to fresh cells, and cell filterability index (RFI) are observed over the data shown in the preceding Tables  
20   4-6. We propose that the combined advantages of the highly permeant polyalcohols with permeant and impermeant carbohydrates (both monosaccharides and disaccharides) and polymers having high component Tg values, allows for the recovery of thawed  
25   reconstituted human red cells having excellent cell preservation qualities following frozen storage at temperatures as high as -22°C.

#### Example 6

In this example we extend the application of glass  
30   transition theory to freeze-drying of human red blood cells (freeze-drying can be achieved by direct sublimation, in which water vapor is removed from a

frozen sample whose temperature is held under the  $T_g'$  of the composition, or also by evaporative drying, herein defined as removal of water vapor from samples having temperature above the  $T_g'$ ).

- 5 In Table 10 we explored the use of cryostabilizing buffers containing 25% (v/v) starting concentration of glycerol as the permeant cryoprotectant, in combination with various carbohydrates (both mono- and disaccharides) and polymers. In these buffers we
- 10 focused on the application of hydroxyethylstarch (HES) as the polymer, having average molecular weights of 200,000 and 500,000 to elevate the buffer  $T_g'$  as predicted by glass transition theory. For comparison to the HES polymer (which has the added
- 15 advantage of USP pharmaceutical grade), we examined several starch hydrolysis products prepared from natural starches (i.e., potato starch), commonly used in food product formulations. The starch hydrolysis products examined included SPG20 and Paselli MD10.
- 20 For these experiments the human red blood cells were mixed with each of the buffers listed in Table 10, frozen, and then subjected to freeze-drying at a starting freeze-dryer shelf temperature of  $-25^{\circ}\text{C}$ . We use a Virtis shelf lyophilizer in this process.
- 25 During the drying process the shelf temperature is ramped to  $+4^{\circ}\text{C}$  without causing sample fluidity. This is consistent with glass transition theory, as we expect the  $T_g'$  of the initially frozen composition to increase as water is removed during the freeze-
- 30 drying. Hence the lyophilizer shelf temperature (and the sample temperature) can be raised as drying proceeds without causing sample fluidity and collapse. We monitored the amount of water removed from the samples by weight loss, and determined that
- 35 in all cases at least 90% of the water initially

present was removed (the solutes and cells being non-volatile). The dried samples were rehydrated and subjected to analysis as described in Tables 4-9.

In Table 10 each buffer formulation is designated by a number (i.e., SB 1965 -SB 1978). The components of each aqueous system, in addition to the 25% v/v glycerol present in each are shown (all percentages are percent w/v). As a control, buffer SB 1965 contains only 25% glycerol in 40 mM phosphate buffer, pH 7.4 (all other buffers in Table 10 are made in 40 mM phosphate pH 7.4). As further controls, SB 1966 and SB 1967 contain 15% w/v SPG20 or 7.5% Paselli, respectively, which are hydrolysis products of natural starches.

From Table 10 it can be seen that SB 1909 in particular confers significant protection to the dried red blood cells, as seen from the high osmotic stability in saline (88.8% of the cells survive exposure to physiological saline), normal red cell indices (MCV, MCH, MCHC), and improved deformability (Dimax = 92.6% of the value normally detected in fresh red cells). The filterability of these cells is also improved to some 50% of fresh red cell values. This sample was determined to have lost at least 90% of its moisture (i.e., contained 10% or less residual moisture) after drying. Buffer SB 1909 contains 25% (v/v) glycerol, .5% (w/v) glucose, 2.25% (w/v) lactose, and 7.25% (w/v) hydroxyethylstarch (HES-500 of 500,000 average molecular weight). This formulation illustrates the essential principles of the present invention: use of a highly membrane permeable component (glycerol), in combination with a membrane permeable monosaccharide (glucose), an impermeable disaccharide (lactose), and a high

molecular weight polymer (HES) to elevate the  $T_g$  of the multicomponent buffer.

In Figure 3 we show a representative osmoscan profile for the rehydrated red cells in sample SB 1909. The thin-line trace is the response observed with fresh control human red blood cells. The bold-type trace is the response of human red cells dried to at least 10% residual moisture at shelf temperatures ranging from  $-25^{\circ}\text{C}$  and  $+4^{\circ}\text{C}$ , and then rehydrated to yield intact and viable red blood cells. From this osmoscan profile it can be seen that the maximum average cell deformability ( $DI_{\text{max}}$ ), corresponding to the peak curve height, is very close (92.6% in Table 10) to that of fresh red cells. In addition, the overall curve profile is very near to that of fresh red cells. From our past experience with this method, we know that grossly rigid, damaged cells or cell debris yield a flat osmoscan profile, with a  $DI_{\text{max}}$  of 0.3 or less (data not shown). Figure 3 shows that the recovered rehydrated cells exhibit cellular rheology properties very similar to those of normal, untreated red cells, and this suggests that these cells retain the flexibility needed to survive circulation in the microvasculature following transfusion.

#### Example 7

In Table 11 we used fresh or one day-old human platelet concentrates to evaluate several polyvinylpyrrolidone (PVP) based cryostabilizing formulations. We combined different carbohydrates with the polymer, including monosaccharides and disaccharides. Hence the monosaccharide provides a membrane permeant cryoprotectant while the polymer and disaccharide are extracellular protectants. All

of the PVP-based formulations used with human platelet concentrates comprised a 10,000 average molecular weight PVP (PVP-10). We add these cryoprotectants directly to platelet concentrates in autologous plasma, which contains a buffering system, hence the formulations tested in Table 11 are prepared in 10 mM phosphate buffers, pH 7.2.

In Table 11 we show different cryoprotectant formulations comprising trehalose (tre), glucose (gluc), mannose (man), and/or lactose (lac), expressed in w/v percentages. We mix each buffer in a 1:1 proportion by volume with human platelet concentrate, and all w/v percents given in Table 11 refer to the final component concentration in the mixture of cryoprotectant solution and platelet concentrate. We examined cryoprotectant formulations containing one, two, or three primary cryoprotective components (i.e., carbohydrate or polymer alone, carbohydrate plus polymer, and carbohydrate mixtures plus polymer).

Samples of each mixture of cells and cryoprotectants were frozen at 10°C/minute in a controlled rate freezer to -60°C, and then transferred for storage to either a -80°C or a -40°C freezer. Samples were stored for 4-6 days. Each sample was then thawed in a 37°C water bath, diluted in phosphate buffered saline (PBS) to enable aggregometry analysis (the PVP must be diluted for proper assay conditions), and the cells recovered by centrifugation.

In this example and in the following examples herein, a standard set of cell quality assays are performed on the recovered cells. In Table 11 and our other platelet data herein, we show comparable

values obtained from control, untreated fresh platelet concentrates ("FRESH"). Our reported values are the mean  $\pm$  the standard error of the mean (SEM). These assays include:

- 5 1) Cell number recovery based on light microscopic examination and counting of the cells.
- 2) Cell morphology based on light microscopic examination and using the scoring method of Kunicki et al. (1975) Transfusion vol. 15, 414-421.
- 10 3) Aggregometry analysis using a Chronolog Lumi-Aggregometer to measure the normal platelet aggregation response to exogenous agonists. We measure the cell response to three treatments: adenosine diphosphate (ADP) + calcium, ristocetin (an  
15 antibiotic that causes platelet aggregation), and collagen (the natural substrate that activates platelet aggregation).
- 4) Hypotonic shock response (HSR), stresses the platelets under hypotonic conditions to measure the  
20 degree of cell flexibility. Healthy cells are able to withstand the shock and shrink to their normal cell volume upon return to isotonic conditions.

The data in Table 11 show that the formulations tested were comparable in preserving the measured in  
25 vitro properties following frozen storage at -80°C for 4-6 days. In all cases the post-thaw assay values were about 50% of the control values observed in fresh, untreated platelet concentrates. Reduction in the hypotonic shock response is noted.

In Table 12 we compared the properties of human platelets frozen and stored at  $-80^{\circ}\text{C}$ , and then thawed and assayed as described in Example 1. We compared the trehalose/mannose/PVP-10 (TMP) formulation and  
5 the lactose/mannose/PVP-10 (LMP) formulation from Example 1 to dimethylsulfoxide (DMSO) or glycerol formulations reported in the blood banking literature. Due to the low glass transition  
10 temperature of 5% DMSO, cells stored in this medium are normally maintained at  $-80^{\circ}\text{C}$ . We observed that the glycerol/glucose formulation resulted in the lowest cell recovery (this highlights the cell-type specificity of cryoprotectant formulation, as our red  
15 cell examples herein show the efficacy of low concentrations of glycerol (18-25% v/v) in red cell preservation). The mono- and disaccharide PVP buffers appear comparable in cell recovery to 5% DMSO at the selected storage temperature.

#### Example 9

20 In Table 13 we repeated the experiment shown in Table 12, but stored the platelet concentrates at  $-40^{\circ}\text{C}$ . The TMP and LMP formulations both have  $T_g' > -40^{\circ}\text{C}$ , while the standard glycerol or DMSO solutions have  $T_g' \ll -40^{\circ}\text{C}$  (for both the TMP and LMP  
25 formulations the measured  $T_g'$  by differential scanning calorimetry was about  $-31^{\circ}\text{C}$ ). The frozen samples were stored for 5-7 days. The resulting data show that the high  $T_g'$  TMP and LMP formulations yield better cell morphology and superior cell aggregation  
30 responses than the DMSO frozen cells. This suggests that frozen cell storage at temperatures much higher than conventional liquid nitrogen storage or  $-80^{\circ}\text{C}$  mechanical freezer storage can be achieved by careful use of glass transition theory in cryoprotectant  
35 medium formulation.



Example 10

To extend the study in Example 9, we again prepared fresh, one day-old human platelet concentrates mixed 1:1 by volume with the lactose/mannose/PVP- 10 formulation (LMP) as described in Example 1 (the solution is formulated as 10% w/v lactose, 5% w/v mannose, 10% w/v PVP-10,000 mM in 10 MW phosphate buffer, pH 7.2, and is diluted into an equal volume of platelet concentrate). We then compared the ability of this formulation to preserve human platelets at elevated frozen storage temperatures as high as -25°C, relative to standard 5% DMSO. In this experiment four independent samples were prepared and frozen for each parameter (fresh controls, DMSO, and LMP), and then stored at three different temperatures: -80°C, -38°C, and -25°C. In Table 14 we show the data obtained after the frozen platelets were stored for 7 days at each temperature, and then thawed and prepared for aggregometry analysis by a single centrifugation step to remove most of the cryoprotectants. In Table 4 the aggregation response values are expressed as chart percentages. Morphology score and percent cell recovery are obtained as described in Example 7.

The data in Table 4 show that DMSO alone fails to adequately preserve measurable in vitro platelet responses, as well as cellular integrity, at elevated frozen temperatures. The high Tg' LMP formulation (Tg' approximately -31°C) yields improved functional responses after storage at -38°C and -25°C relative to DMSO.

Table 1.

## DSC Studies

Several buffer preparations were examined to determine their glass transition temperatures. A summary of the observed values is included in the following table:

<u>Buffer</u>		<u>Tg' Observed</u>		<u>Tg' Pre-dicted</u>
10	5% Glucose, 10% lactose, 20% Dextran40	-26.5	-25.5	
	5% Glucose, 10% Lactose, 15% Dextran40	-25.5	-27.2	
	5% Glucose, 10% FCS, 20% Dextran40	-24.0	--	
	5% Glucose, 10% Lactose, 20% PVP40	-32.8	-31.2	
	5% Glucose, 10% Lactose, 15% PVP40	-31.0	-32.2	
15	5% Glucose, 10% Lactose, 20% HES200	-30.0	-28.4	
	0-5M Glycerol, 7.5% BSA, 0.3M Glucose	-52.0	-51.0	
	0.5M Glycerol, 0.3M Glucose	Less than -60	-101	

## Legend to Table 1.

The predicted Tg' values were derived using Equation 1 for the individual components listed. Each buffer also contained buffer salts and metabolites as listed below (Basic Buffer Salts) whose contribution to calculated Tg' is ignored for the purpose of estimating Tg'. The measured Tg' values were obtained by DSC analysis of 2.3:1 dilutions of buffer:water to approximate the ratio of buffer:cell suspension used for cryostabilization of human red blood cells.

Basic Buffer Salts:

30	1.5 mM KH <sub>2</sub> PO <sub>4</sub>	0.75 mM glutamine
	8.1 mM Na <sub>2</sub> HPO <sub>4</sub>	0.75 mM nicotinic acid
	0.49 mM MgCl <sub>2</sub>	10 mM glutathione
	10 mM inosine	pH = 7.4
	5 mM adenine	

35 Dextran 40 = dextran 40,000 MW (av)

PVP 40 = polyvinylpyrrolidone 40,000 MW (av)  
 FCS = fetal calf serum  
 HES = hydroxyethyl starch 200,000 MW (av)  
 BSA = bovine serum albumin

5

Table 2.

Three Component Buffers for  
 Red Blood Cell Cryopreservation.

<u>Buffer Components@</u>		<u>Calculated+ Tg' (°C)</u>	<u>Measured* Tg' (°C)</u>
10	1) 5% mannose/10% lactose/ 20% PVP-40	-30.7	-30.0, -30.25
	2) 5% fructose/10% lactose/ 20% PVP-40	-30.8	N.D.(1)
	3) 5% glucose/10% lactose/ 20% PVP-40	-31.2	-30.5, -31.0
15	4) 5% mannose/10% trehalose/ 20% PVP-40	-31.1	N.D.
	5) 5% fructose/10% trehalose/ 20% PVP-40	-31.2	N.D.
20	6) 5% glucose/10% trehalose/ 20% PVP-40	-31.4	-32.1 (n=1)
	7) 5% mannose/10% sucrose/ 20% PVP-40	-31.8	N.D.
	8) 5% glucose/10% sucrose/ 20% PVP-40	-32.1	N.D.
25	9) 5% fructose/10% sucrose/ 20% PVP-40	-31.9	N.D.

@ All buffers include the Basic Salts listed in Table 1 herein. All percentages are (w/v) percents; PVP-40 is 40,000 average MW polyvinylpyrrolidone.

+ Calculated Tg' values from Equation 1 herein, taking buffer dilution into account.

\* Measured Tg' values from DSC analysis on 2.3: 1 mixtures of buffer:water; separate values are shown from two independent measurements.

(1)N.D. = Not determined. From our data in Table 3 and buffers #1,3,6 above we find good correlation between calculated and DSC measured Tg' values.

35

Table 3.

Buffer Tg' Adjustment by Selection of Solute Components.

	<u>Buffer Components</u>	<u>Calculated Tg' (°C)</u>	<u>Measured Tg' (°C)</u>
5	10% glucose/10% lactose/ 20% PVP-40	-33.6	-33.0, -33.5
	10% glucose/10% lactose/ 20% HES-500	-31.2	-31.5, -31.75
10	5% glucose/10% lactose/ 20% PVP-40	-31.2	-30.5, -31.0
	5% glucose/10% lactose/ 10% dextran-40	-29.6	-30.25, -30.25
15	5% glucose/10% sucrose/ 20% dextran-40	-26.1	-26.0, -26.5
	5% mannose/10% sucrose/ 20% dextran-40	-25.8	-24.0, -23.75
	5% mannose/10% trehalose/ 20% dextran-40	-25.1	-23.75, -24.0
20	5% glucose/20% dextran-40	-22.4	-21.25, -21.25

All buffer components are expressed as (w/v) percentages, and are made in the Basic Salts formulation as outlined in Table 1. Calculated and measured buffer Tg' values are derived as outlined in

25 Table 1.

TABLE 4  
 PROPERTIES OF RED CELLS STORED AT -80°C OR -38°C:  
 BUFFERS 1-3

	Expected Values	Buffer #1 @ -80C n=2	Buffer #1 @ -38C n=2	Buffer #2 @ -80C n=2	Buffer #2 @ -38C n=2	Buffer #3 @ -80C n=2	Buffer #3 @ -38C n=2
Recov at Recon %	90% or greater	94.2	87.1	95.4	83.4	96.1	84.2
Overall Recov %	80% or greater	84.5	71.6	86.7	65.2	90.8	69.4
Osmotic Stability%	70% or greater	65.6	34.1	49.4	36.1	61.0	43.7
MCV (fl)	80-100	83.0	85.0	99.1	100.1	96.4	98.8
MCH (pg)	25-35	27.8	27.3	29.7	27.9	29.6	29.3
MCHC %	31-37	33.4	32.3	30.0	27.9	30.7	29.6
OXHb%	100	83.2	84.0	74.4	88.5	76.3	82.8
METHb%	0	0	0		0	0	
HEMICH	0%	15.8%	16.0%	25.6%	11.5%	23.8%	17.2%
DI max	0.500 or greater	0.505	0.385	0.472	0.425	0.493	0.421
% Contr DI	80% or greater	82.4	62.8	72.1	64.8	75.2	64.2
Osmoscan	Normal	Good but no Omin	Good but no Omin	Good but no Omin	Good but no Omin	Good but no Omin	Good but no Omin
RFI	0.650- 0.700	ND	ND	0.350	0.310	0.384	0.309
%Contr RFI	80% or greater	ND	ND	37.2	34.3	42.6	34.2
Density g/ml	1.095 or greater	1.103	1.105	1.101	1.098	1.101	1.099

TABLE 5  
 PROPERTIES OF RED CELLS STORED AT -80°C OR -38°C:  
 BUFFERS 4-6

	Expected Values	Buffer #4 @ -80C n=2	Buffer #4 @ -38C n=2	Buffer #5 @ -80C n=2	Buffer #5 @ -38C n=2	Buffer #6 @ -80C n=2	Buffer #6 @ -38C n=2
Recov at Recon %	90% or greater	93.9	78.1	94.9	30.5	95.6	76.1
Overall Recov %	80% or greater	84.4	57.6	87.2	64.0	81.0	54.4
Osmotic Stability %	70% or greater	52.0	35.3	54.0	37.6	60.0	28.4
MCV (fl)	80-100	97.9	101.6	97.6	99.1	96.9	102.3
MCH (pg)	25-35	29.5	29.5	29.6	29.5	29.3	29.1
MCHC %	31-37	30.1	29.1	30.3	29.8	30.4	28.3
OXYHb	100%	76.3	82.3	75.8	78.8	80.4	76.9
METHb	0%	0	0	0	12.9	0	0
HEMICH	0%	23.7%	17.7%	24.2	8.3%	19.6%	23.1%
DI <sub>max</sub>	0.500 or greater	0.509	0.432	0.467	0.419	0.512	0.422
%contr DI	80% or greater	77.8	65.9	71.2	64.0	78.2	64.5
Osmoscan	Normal	Good but no Omin	Good but no Omin	Abnormal	Abnormal	Good but no Omin	Abnormal
RFI	0.650- 0.700	0.314	0.268	0.364	0.319	0.442	0.317
%contr RFI	80% or greater	38.7	29.7	40.3	35.3	49.0	35.1
Density z/ml	1.095 or greater	1.098	1.097	1.100	1.097	1.098	1.100

TABLE 6  
 PROPERTIES OF RED CELLS STORED AT -80°C OR -38°C:  
 BUFFERS 7-9

	Expected Values	Buffer # 7 @ -80C n=2	Buffer #7 @ -38C n=2	Buffer #8 @ -80C n=2	Buffer #8 @ -38C n=2	Buffer # 9 @ -80C n=2	Buffer # 9 @ -38C n=2
Recov at Recon %	90% or greater	95.7	77.2	91.1	87.1	94.3	79.4
Overall Recov %	80% or greater	85.1	55.7	78.4	71.9	81.2	57.3
Osmotic Stability%	70% or greater	60.3	40.5	57.6	29.7	59.8	27.2
MCV (fl)	80-100	95.9	98.1	83.5	83.5	83.5	84.5
MCH (pg)	25-35	30.7	29.9	27.8	27.4	27.7	27.1
MCHC %	31-37	32.0	30.5	33.3	32.8	33.2	32.2
OXYHb	100%	70.9	81.5	88.0	88.1	88.9	84.6
METHb	0%	0	0	0	0.150	0	
HEMICH	0%	39.1%	18.6%	12.0%	11.7%	11.1%	15.4%
DI <sub>max</sub>	0.500 or greater	0.518	0.446	0.478	0.362	0.449	0.344
%contr DI	80% or greater	79.0	68.0	78.2	59.1	73.3	56.2
Osmoscan	Normal	Good but no Omin	Abnormal	Good but no Omin	Abnormal	Good but no Omin	Abnormal
RFI	0.650- 0.700	0.479	0.334	ND	ND	ND	ND
%contr RFI	80% or greater	53.1	37.0	ND	ND	ND	ND
Density g/ml	1.095 or greater	1.099	1.102	1.103	1.105	1.106	1.088

TABLE 7

Summary of the results obtained with RBC stored at -22C in glycerol based cryobuffers. Note that the blood to buffer ratio for all the experiments is 1:3.

	Expected Values	25% Gly Stored at -22C for 15hrs	75% HES 25% Gly 15hrs at -22C	15% PVP +25% Gly 15hrs at -22C	7.5% PVP +25% Gly 15hrs at -22C	7.5% Lac +25% Gly 15hrs at -22C	7.5% Sucr +25% Gly 15hrs at -22C	5% Plur + 25% Gly 15hrs at -22C	7.5% Dex +25% Gly 15hrs at -22C
Recovery at Recon	90% or greater	98.1	95.5	94.7	89.6	97.6	95.2	97.8	93.5
Overall Recovery	80% or greater	91.7	74.1	85.5	71.4	93.5	90.0	89.5	74.7
Osmotic Stability	70% or greater	97.7	91.2	97.0	94.7	97.9	95.7	95.2	95.4
E	56.0 or greater	89.6	67.8	82.9	67.6	91.5	86.1	85.2	71.3
MCV (fl)	80-100	91.4	93.1	93.0	92.1	91.8	92.9	92.1	92.5
MCH (pg)	25-35	30.1	29.4	31.3	29.6	31.4	31.0	30.6	30.5
MCHC (g/dL)	31-37	33.0	31.6	33.6	32.2	34.3	33.3	33.1	33.0
DI <sub>max</sub>	0.500 or greater	0.657	0.645	0.636	0.630	0.643	0.613	0.639	0.662
%Control DI <sub>max</sub>	80% or greater	100	100	99.2	98.3	100	95.6	99.7	100
Osmscan	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
RFI	0.700 or greater	0.940	0.860	0.840	0.800	0.900	0.880	0.840	0.860
%Control RFI	100	98.2	89.9	87.8	83.6	94.0	92.0	87.8	89.9
# of Samples	n=6	n=1	n=1	n=1	n=1	n=1	n=1	n=1	n=1

Abbreviations: Gly, Glycerol; Plur, Pluronic acid; Dex, Dextran 40; HES, Hydroxyethylstarch 250,000; Lac, Lactose; Sucr, Sucrose.



TABLE 8

Summary of the results obtained with RBC stored at -22C for 4 days. Note that the blood to buffer ratio for all the experiments is 1:3

	Expected Values	25%Gly Stored at -22C for 4days	75% HES 25%Gly at -22C for 4days	15%PVP +25%Gly at -22C for 4days	7.5%PVP +25%Gly at -22C for 4days	7.5%Lac +25%Gly at -22C for 4days	7.5%Sucr +25%Gly at -22C for 4days	5%Plur + 25%Gly at -22C for 4days	7.5%Dex +25%Gly at -22C for 4days
Recovery at Recon	90% or greater	92.9	94.9	95.3	92.4	92.7	92.3	93.7	90.6
Overall	80% or greater	87.4	82.3	87.4	78.8	88.8	86.3	84.5	65.5
Recovery	80% or greater	97.4	97.6	95.2	96.5	96.6	95.4	95.4	94.5
Osmotic Stability	70% or greater	85.1	80.3	83.2	76.0	85.8	82.3	80.6	61.9
E	56.0 or greater	91.9	92.5	93.6	93.4	92.2	92.0	91.7	92.0
MCV	80-100	31.0	30.4	32.1	30.2	30.9	30.6	30.3	30.0
MCH	25-35	33.6	32.9	34.4	32.3	33.5	33.2	33.0	32.6
MCHC	31-37	0.656	0.634	0.617	0.631	0.533	0.466	0.602	0.662
(g/dL)	0.500 or greater	100	98.9	96.3	98.4	82.8	72.7	93.9	100
Dlmax	80% or greater	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
%Control	Normal	0.907	0.840	0.800	0.860	0.740	0.760	0.860	0.840
RFl	0.700 or greater	94.8	87.8	83.6	89.9	77.3	79.4	89.9	87.8
%Control RFl	80% or greater	n=1	n=1	n=1	n=1	n=1	n=1	n=1	n=1
# of Samples	n=6								

Abbreviations: See Table 7

TABLE 9

Effects of 1,2-propanediol on the properties of cells stored at -22C. Table also shows a summary of the results obtained with 20% glycerol in combination with either lactose or 40K PVP. Note that the blood to buffer ratio for all the experiments is 1:3. Note also that some of the RBC were rapidly frozen at -80C and then stored at -22C for 15 hours.

	Expected Values	25% 1,2-propane-diol . 15hrs at -22C	15%PVP + 25%Pvp 15hrs at -22C	7.5%Lact +25%Pvp 15hrs at -22C	7.5%Lact +20%Gly 15hrs at -22C.Slow freeze to -20C	7.5%Lact +20%Gly 15hrs at -22C. Fast frozen to -80C	15%PVP+ 20%Gly 15hrs at -22C. Slow freeze to -20C	15%PVP+ 20%Gly 15hrs at -22C. Fast freeze to -80C
Recovery at Recon	90% or greater	97.5	97.5	88.7	92.9	88.6	95.1	86.2
Overall Recovery	80% or greater	95.2	90.5	83.7	88.3	59.5	80.4	49.7
Osmotic Stability	70% or greater	93.8	96.7	94.8	97.4	93.4	96.9	94.3
E	56.0 or greater	89.3	87.5	79.4	86.0	55.6	77.9	46.9
MCV (fl)	80-100	94.7	94.2	90.1	84.6	91.9	86.6	90.8
MCH (pg)	25-35	31.0	30.1	31.4	30.3	25.8	28.3	25.0
MCHC (g/dL)	31-37	32.8	32.0	34.9	35.8	28.1	32.7	27.6
Dlmax	0.500 or greater	0.639	0.639	0.540	0.589	0.642	0.598	0.633
%Control Dlmax	80% or greater	99.7	99.7	84.2	92.6	100	94.0	99.5
Osmscan	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
RFI	0.700 or greater	0.917	1.0	0.720	0.920	0.600	0.940	0.608
%Control RFI	80% or greater	93.6	100	73.5	96.0	62.8	98.3	63.6
# of Samples	n=6	n=1	n=1	n=1	n=1	n=1	n=1	n=1

Abbreviations : See Table 7

TABLE 10

	SB 1965	SB 1966	SB 1967	SB 1969	SB 1970	SB 1971	SB 1972	SB 1978- 20	SB 1978- 10
Comp (all w/ 25% Gly)	25% Gly alone	15% SPG 20	7.5% pasel	0.5 G 2.25L 7.25H 200K	.05G .65L 9.3H 500K	.15G 1.15L 8.2H 500K	0.5G 2.25L 7.25H 500K	2.0G 6.0L 12.0H 200K	1.0G 3.0L 6.0H 200K
%Dry	90	90	90	90	90	90	90	90	90
Rec	8.4	17.5	21.1	50.6	29.8	19.5	53.5	39.0	54.1
Osm	58	81	77.3	85.8	64.7	66.9	88.8	60.3	84.1
Stab									
MCV	93.2	102.1	96.4	104.8	98.0	96.1	94.5	95.9	96.4
MCH	10.4	29.3	14.1	29.2	27.0	28.0	31.0	29.2	30.2
MCHC	11.2	28.7	14.7	27.8	27.6	29.1	32.8	30.4	31.3
DI	-	80.7	60.7	85.3	-	-	92.6	81.0	88.5
Max	-	-	-	-	-	-	50.0	32.0	50.0
Filter	-	-	-	-	-	-	-	-	-

Legend to Table 10

gly = glycerol

SPG20, Paselli = natural starch hydrolysis products

G = glucose

L = lactose

H 500K = hydroxyethyl starch 500,000 MW

H 200K = hydroxyethyl starch 200,000 MW

% DRY - % dryness by weight

(all numbers for individual buffer components are % w/v for solids and % v/v for glycerol)

TABLE 11

Comparison of PVP buffers  
Storage at -80°C for 4 to 6 days

TABLE

N=4	FRESH	Single component		Two components		Three components		
		Trichalose 10%	PVP 10%	PVP 10% Gluc 0.6M	PVP10% Man.2.5% Trc. 5%	PVP10% Man.2.5% Lac. 5%		
REcovery SEM	100.00	34.63	42.25	60.27	43.25	44.83		
	0.00	4.60	3.17	16.23	6.71	2.47		
Morphology SEM	189.00	92.25	113.25	68.75	104.00	99.25		
	29.54	12.97	8.99	17.97	7.31	7.00		
ADP+ca SEM	70.93	31.15	32.83	5.33	23.78	27.23		
	6.12	2.94	4.02	2.74	3.76	3.61		
Collagen SEM	84.05	46.78	51.83	19.40	38.75	38.48		
	3.00	4.12	5.68	3.96	2.53	3.78		
Ristocetin SEM	83.10	32.00	36.23	30.53	26.38	29.18		
	3.91	6.39	1.60	11.23	4.72	3.30		
HSR SEM	41.30	4.93	7.53	5.47	2.15	1.18		
	11.05	3.06	3.87	2.39	1.86	1.02		

Recovery = Numerical recovery  
Aggregation induced by ADP+Calcium, Collagen, Ristocetin.  
HSR = Hypotonic shock response

TABLE 12

TABLE

Comparison DMSO or Glycerol buffers with Cryopropharm buffers at  $-80^{\circ}\text{C}$ 

N=4	FRESH	Cryopropharm buffers			
		DMSO 5%	Glyc. 5% Gluc. 0.6M	TMP 10%	LMP 10%
REcovery SEM	100.00 0.00	61.63 6.53	33.80 7.92	43.25 6.71	44.83 2.47
Morphology SEM	189.00 29.54	89.00 14.34	69.67 13.68	104.00 7.31	99.25 7.00
ADP+ca SEM	70.93 6.12	21.53 6.90	4.40 1.34	23.78 3.76	27.23 3.61
Collagen SEM	84.05 3.00	36.93 5.89	10.50 4.55	38.75 2.53	38.48 3.78
Ristocetin SEM	83.10 3.91	35.58 6.65	46.60 6.72	26.38 4.72	29.18 3.30
HSR SEM	41.30 11.05	2.08 1.04	10.53 6.21	2.15 1.86	1.18 1.02

TABLE 13

TABLE

Study of stability at different temperature

Storage at -40C

N=4	FRESH	Storage at -40C		
		DSMO 5%	TMP 10%	LMP 10%
REcovery SEM	100.00 0.00	44.23 5.39	36.48 2.88	43.00 2.38
Morphology SEM	189.00 29.54	38.00 1.27	73.75 4.52	65.50 4.37
ADP+ca SEM	70.93 6.12	5.83 1.92	14.48 2.81	15.20 1.79
Collagen SEM	84.05 3.00	14.13 3.64	33.03 3.79	33.10 3.51
Ristocetin SEM	83.10 3.91	6.00 2.10	14.50 2.13	13.18 1.27
HSR SEM	41.30 11.05	0.00 0.00	0.00 0.00	0.00 0.00

TABLE 14

## Storage at -80°C (n=4).

Cell Property	Fresh Controls	-80°C	
		DMSQ	LMP
Cell Recovery	100	55.6 ± 5.3	45.2 ± 3.3
Morphology Score	184 ± 39	88 ± 19	91 ± 2
ADP Response	76.7 ± 4.8	27.9 ± 5.6	26.2 ± 4.7
Collagen Response	85 ± 3.8	37.2 ± 7.8	37.6 ± 4.9
Ristocetin Response	85.8 ± 4.2	33.3 ± 8.5	28.2 ± 4.3
HSR	51.2 ± 9.2	1.3 ± 1.1	1.6 ± 1.3

## Storage at -38°C (n=4).

Cell Property	Fresh Controls	-38°C	
		DMSQ	LMP
Cell Recovery	100	43.2 ± 7.1	44.4 ± 2.7
Morphology Score	184 ± 39	38 ± 1.7	63.3 ± 5.3
ADP Response	76.7 ± 4.8	5.1 ± 2.4	13.6 ± 1.5
Collagen Response	85 ± 3.8	11.3 ± 3.6	34.1 ± 4.5
Ristocetin Response	85.8 ± 4.2	5.9 ± 2.8	12.1 ± 1.2
HSR	51.2 ± 9.2	0	0

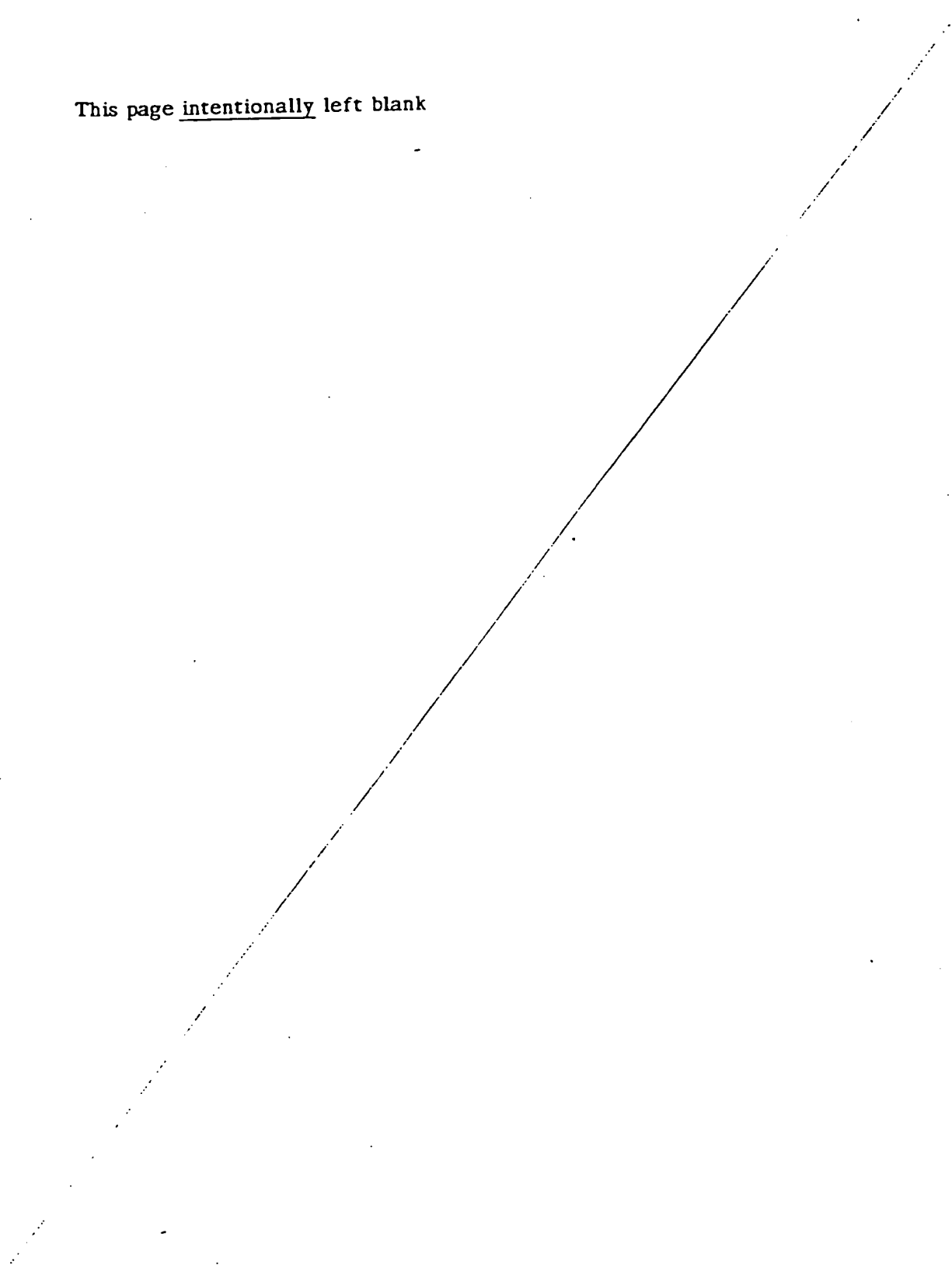
(Table 14, cont.)  
Storage at -25°C (n=4).

	Fresh Controls	-25°C	
		DMSO	LMP
Cell Recovery	100	0	36.9 ± 3.3
Morphology Score	184 ± 39	0	20 ± 2.1
ADP Response	76.7 ± 4.8	0	3.2 ± 0.6
Collagen Response	85 ± 3.8	0	13.8 ± 0.9
Ristocetin Response	85.8 ± 4.2	0	0
HSR	51.2 ± 9.2	0	0



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## WHAT IS CLAIMED IS:

1. A process for freezing cells, cell membranes or cell-like materials comprising the steps of:
  - freezing an aqueous mixture comprising a plurality of cells, cell membranes or cell-like materials with a cryoprotective component;  
wherein said aqueous mixture is characterized by a glass transition temperature of above about  $-60^{\circ}\text{C}$ ;  
said cryoprotective component comprising a first compound capable of permeating said cells, membranes, or cell-like materials and stabilizing said cells, membranes or cell-like materials for freezing;  
and a second water-soluble compound impermeable to said cells, membranes or cell-like materials; the amount of said second compound in said mixture being in a weight fraction sufficient to overcome the predicted depression in the glass transition temperature of said mixture due to said first compound;
  - wherein said freezing is performed by lowering temperature of said mixture to, or less than said glass transition temperature of said mixture, to form a frozen mixture.
2. A process according to Claim 1 further comprising the step of drying said frozen mixture by sublimation or evaporation.
3. A process according to Claim 1 further comprising the steps of:
  - a. maintaining said frozen mixture at frozen storage temperatures at or below said glass transition temperature of said mixture;
  - b. thawing said frozen mixture;
  - c. optionally, reconstituting and/or washing said cells, cell membranes, or cell-like materials.

4. A process according to Claim 1 further comprising the steps of:
- a. drying said frozen mixture by either freeze-drying sublimation or evaporative drying to a dried, solid mixture;
  - b. reconstituting and/or washing said dried solid mixture to recover rehydrated cells, cell membranes, or cell-like materials.
5. A process according to Claims 1, 2, 3, or 4 wherein said cryoprotective component comprises amorphous and/or partially crystalline polymers, or mixtures of different polymers.
6. A process according to Claim 5 wherein said polymers comprise natural and/or synthetic polymers.
7. A process according to Claim 6 wherein said natural and/or synthetic polymers comprise polymers having average molecular weights greater than 300.
8. A process according to Claim 7 wherein said polymer average molecular weights are between 10,000 and 500,000.
9. A process according to Claim 8 wherein said polymers are present in said solution in weight fraction percentages ranging from 1% up to the limit of solubility of said polymer in aqueous solution.
10. A process according to Claim 9 wherein said polymer weight fraction percents are in the range of 5%- 25%.
11. A process according to Claim 6 wherein said natural polymers comprise starch and/or starch hydrolysis products.

12. A process according to Claim 11 wherein said starch comprises hydroxyethyl starch.
13. A process according to Claim 6 wherein said natural polymers comprise proteins, gelatin, dextran,  
5 or other polymers derived from plant, animal, or microbial sources.
14. A process according to Claim 6 wherein said synthetic polymers comprise polyvinylpyrrolidone, polyethylene glycol, or other polymers derived from  
10 organic synthesis.
15. A process according to Claims 1, 2, 3, or 4 wherein said component comprises carbohydrates or mixtures of different carbohydrates.
16. A process according to Claim 15 wherein said  
15 carbohydrates or carbohydrate mixtures comprise monosaccharides and disaccharides.
17. A process according to Claim 16 wherein said monosaccharides and/or disaccharides are each present in a weight fraction percent between 0.01% up to its  
20 solubility limit in aqueous solution.
18. A process according to Claim 17 wherein said weight fraction percent is between 0.5% and 20%.
19. A process according to Claim 16 wherein said monosaccharides are selected from the group  
25 comprising 6 carbon hexose sugars.
20. A process according to Claim 17 wherein said hexose sugars comprise glucose, fructose, galactose, and mannose.

21. A process according to Claim 16 wherein said monosaccharides are selected from the group comprising 5 carbon pentose sugars.
22. A process according to Claim 19 wherein said  
5 pentose sugars comprise ribose, xylose, arabinose, and ribulose.
23. A process according to Claim 16 wherein said disaccharides comprise maltose, lactose, sucrose, and trehalose.
- 10 24. A process according to Claims 1, 2, 3, or 4 wherein said component comprises polyalcohols.
25. A process according to Claim 24 wherein said polyalcohols comprise glycerol and 1,3- propanediol.
26. A process according to Claim 24 wherein said  
15 polyalcohols are present in concentrations between 0.1% and 40% by volume.
27. A process according to Claim 26 wherein said polyalcohols are present in the range of 5%-25% by volume.
- 20 28. A process according to Claims 1, 2, 3 or 4 wherein said component comprises aqueous mixtures of carbohydrates and/or polyalcohols and polymers.
29. A process according to Claim 28 wherein said mixture of carbohydrates and/or polyalcohols and  
25 polymers comprise membrane permeable and membrane impermeable components.

30. A process according to Claim 28 wherein said aqueous mixtures of carbohydrates and/or polyalcohols and polymers further comprise basic salts.
31. A process according to Claim 30 wherein said  
5 basic salts comprise electrolytes, cofactors, metal cations, metabolites, buffer salts, vitamins, and protein or steroid hormones and growth factors.
32. A process according to Claim 30 wherein said  
10 aqueous mixtures of carbohydrates and polymers and basic salts are characterized by a glass transition temperature of  $-60^{\circ}\text{C}$  or higher.
33. A process according to Claim 32 wherein said glass transition temperature occurs between  $-45^{\circ}\text{C}$  and  $+45^{\circ}\text{C}$ .
- 15 34. A process according to Claim 33 wherein said glass transition temperature is determined by thermal analysis.
35. A process according to Claim 34 wherein said thermal analysis measurements comprises differential  
20 scanning calorimetry (DSC).
36. A process according to Claims 1, 2, 3 or 4 wherein said mixture of cells, cell membranes, or cell-like materials and cryoprotective component is characterized by a glass transition temperature of  
25  $-60^{\circ}\text{C}$  or higher.
37. A process according to Claim 36 wherein said mixture has a glass transition temperature between  $-45^{\circ}\text{C}$  and  $+45^{\circ}\text{C}$ .

38. A process according to Claim 37 wherein said glass transition temperature is measured by differential scanning calorimetry.

39. A process according to Claims 1, 2, 3 or 4  
5 wherein said cells comprise mammalian cells.

40. A process according to Claim 39 wherein said mammalian cells comprise human cells.

41. A process according to Claim 40 wherein said human cells comprise solid tissues.

10 42. A process according to Claim 40 wherein said human cells comprise peripheral blood cells.

43. A process according to Claim 42 wherein said peripheral blood cells comprise red blood cells, platelets, stem cells, and leukocytes.

15 44. A process according to Claims 1, 2, 3 or 4 wherein said cell membranes comprise mammalian cell membranes.

45. A process according to Claim 44 wherein said mammalian cell membranes comprise human cell  
20 membranes.

46. A process according to Claim 45 wherein said human cell membranes comprise membranes of peripheral blood cells, including red blood cells, platelets, stem cells, and leukocytes.

25 47. A process according to Claims 1, 2, 3 or 4 wherein said cell-like materials comprise synthetic phospholipid membranes or vesicles.

48. A process according to Claim 47 wherein said vesicles comprise liposomes and liposome encapsulated hemoglobin.

49. A cryoprotectant medium for freezing or freeze-drying cells, cell membranes or cell-like materials comprising a first compound capable of permeating and stabilizing said cells, membranes or cell-like materials for freezing or freeze-drying, and a second water-soluble compound impermeable to said cells, membranes or cell-like materials, wherein the amount of said second compound in said medium is in a weight fraction sufficient to overcome the predicted depression in the glass transition temperature of said medium due to said first compound; said medium having a glass transition temperature of  $-60^{\circ}\text{C}$  or higher.

50. A frozen-thawed composition prepared according to any of Claims 3 or 4.

51. A frozen composition prepared according to the process of Claim 1.

52. A freeze-dried composition prepared according to the process of Claim 2.

53. A composition according to Claim 52 wherein said step of drying is by sublimation.

54. A composition according to Claim 52 wherein said step of drying is by evaporative drying.

55. A medium according to Claim 49 wherein said first compound contains polyhydroxy groups.



56. A medium according to Claim 55 wherein said first compound comprises polyalcohols, monosaccharides, or mixtures thereof.

57. A medium according to Claim 49 wherein said  
5 second compound contains polyhydroxy groups.

58. A medium according to Claim 58 wherein said second compound comprises disaccharides, polymers, or mixtures thereof.

59. A medium according to Claim 58 wherein said  
10 polymers comprise natural starches, starch hydrolysis products, hydroxyethylstarch, or mixtures thereof.

60. A medium according to Claim 49 wherein said second compound comprises synthetic polymers.

61. A medium according to Claim 60 wherein said  
15 synthetic polymers comprise polyvinylpyrrolidone.

62. A frozen-thawed composition according to Claim 50 comprising human cells and/or tissues.

63. A composition according to Claim 62 comprising human red blood cells.

20 64. A composition according to Claim 63 wherein said human red blood cells are characterized by normal red cell indices (MCV, MCH, MCHC), and/or osmotic stability in physiological saline of at least 70%, and/or an ektacytometric  $DI_{max}$  value of at least  
25 0.500.

65. A composition according to Claim 62 comprising human platelets.

66. A composition according to Claim 65 wherein said human platelets are characterized by a measureable aggregometry response to platelet agonists.
67. A composition according to Claim 66 wherein said  
5 agonists comprise collagen, ristocetin, and/or adenosine diphosphate and calcium.
68. A composition according to Claim 51 having a glass transition temperature of above about  $-60^{\circ}\text{C}$ .
69. A composition according to Claim comprising human  
10 cells and/or tissues.
70. A composition according to Claim 52 found by freeze-drying said composition in a frozen state in a temperature range of between about  $-45^{\circ}\text{C}$  and  $45^{\circ}\text{C}$ .
71. A composition according to Claim 52 characterized  
15 by a residual moisture content of 50% or less.
72. A composition according to Claim 52 characterized by a residual moisture content in the range of 1% to 30%.
73. A composition according to Claim 52 characterized  
20 by a glass transition temperature that is above the glass transition temperature of said aqueous mixture.
74. A composition according to Claim 73 having said glass transition temperature of above about  $-40^{\circ}\text{C}$ .
75. A frozen composition of human red blood cells or  
25 platelets comprising an aqueous mixture of polyalcohols and/or carbohydrates and polymers, having a glass transition temperature above about  $-60^{\circ}\text{C}$ .

76. A freeze-dried composition of human red blood cells or platelets comprising an aqueous mixture of polyalcohols and/or carbohydrates and polymers having a glass transition temperature of above about  $-60^{\circ}\text{C}$ .
- 5 77. A freeze-dried composition according to Claim 76 having a glass transition temperature of above about  $-40^{\circ}\text{C}$ .

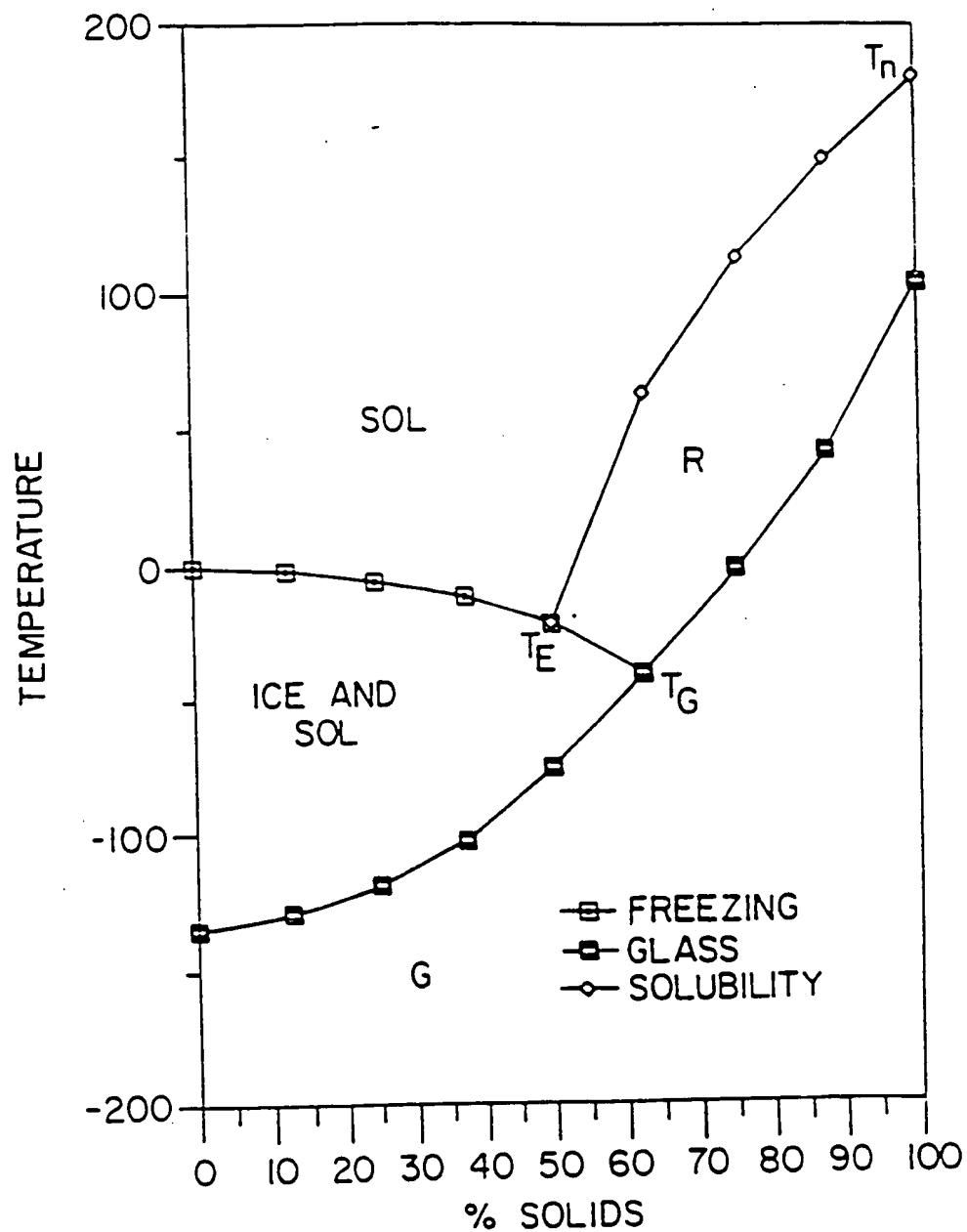
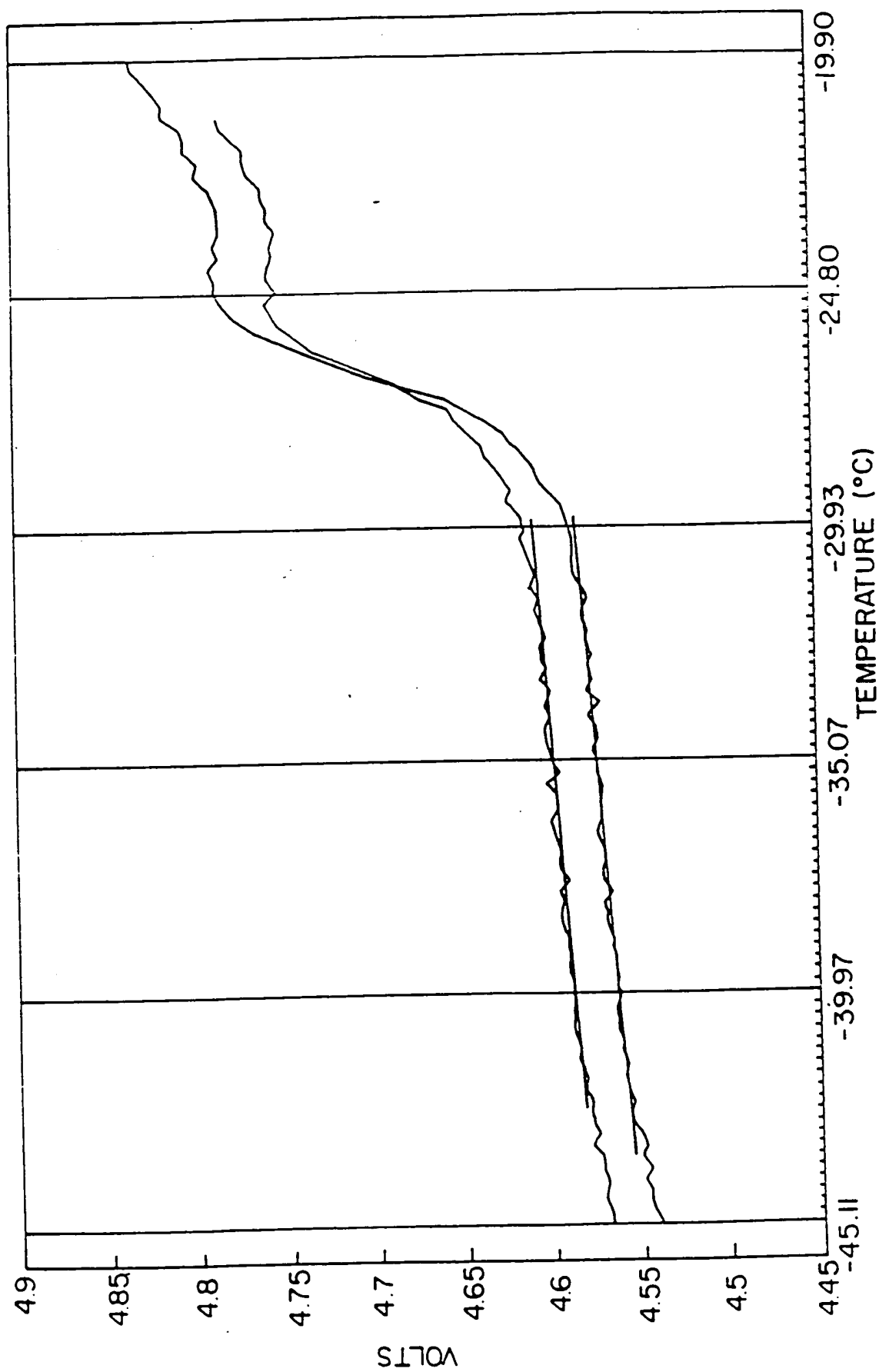


FIG. 1.

**FIG. 2.**

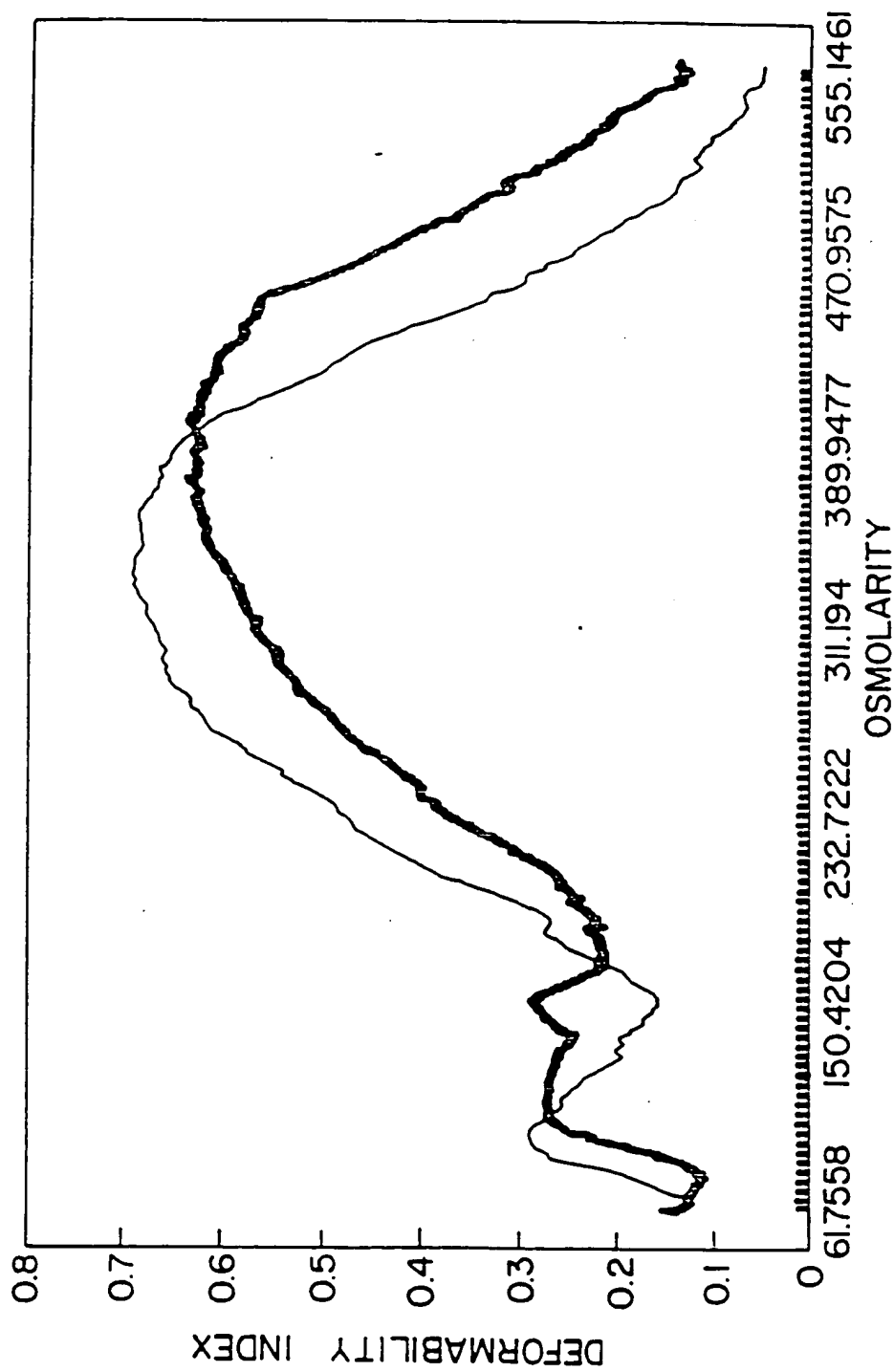
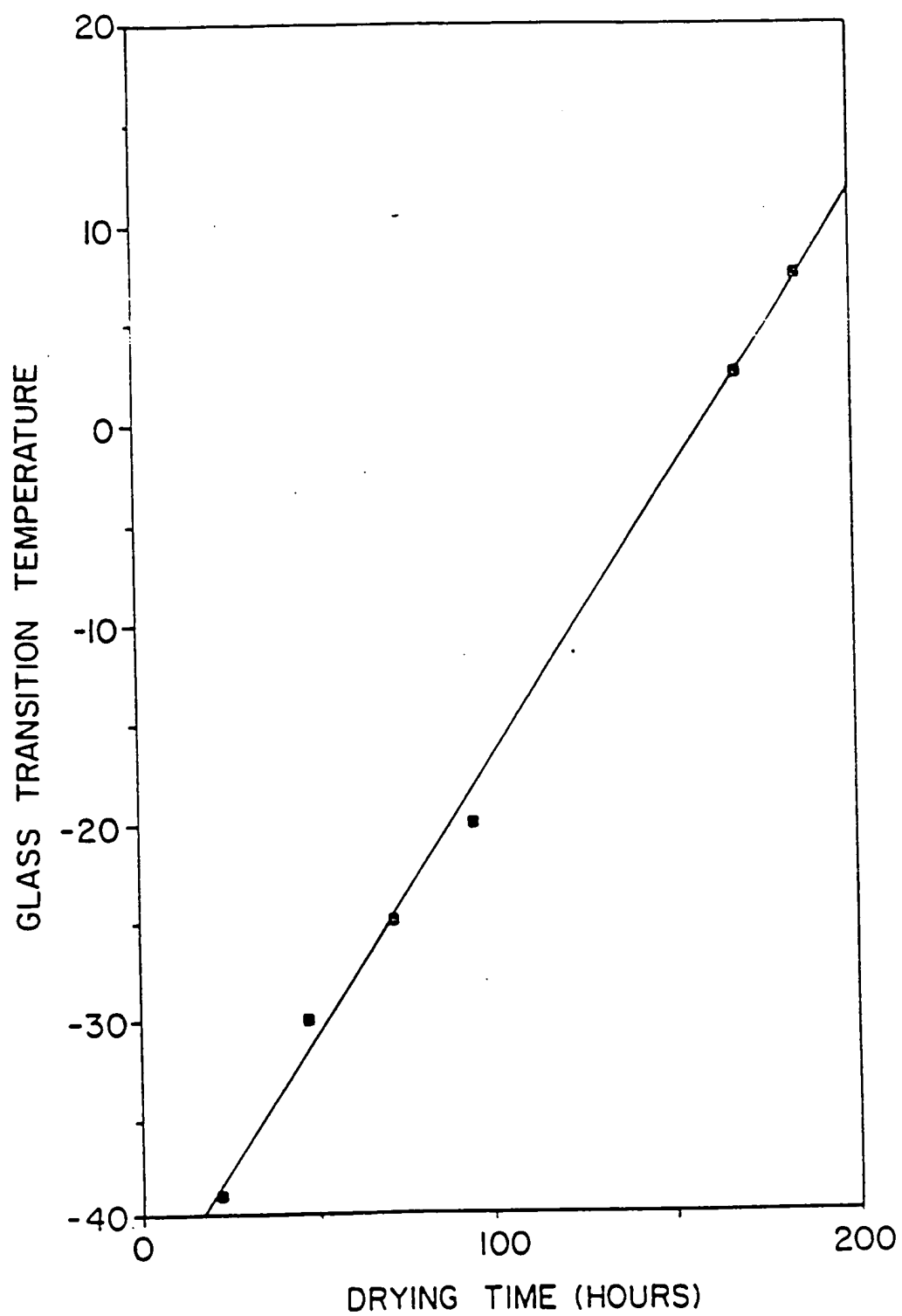
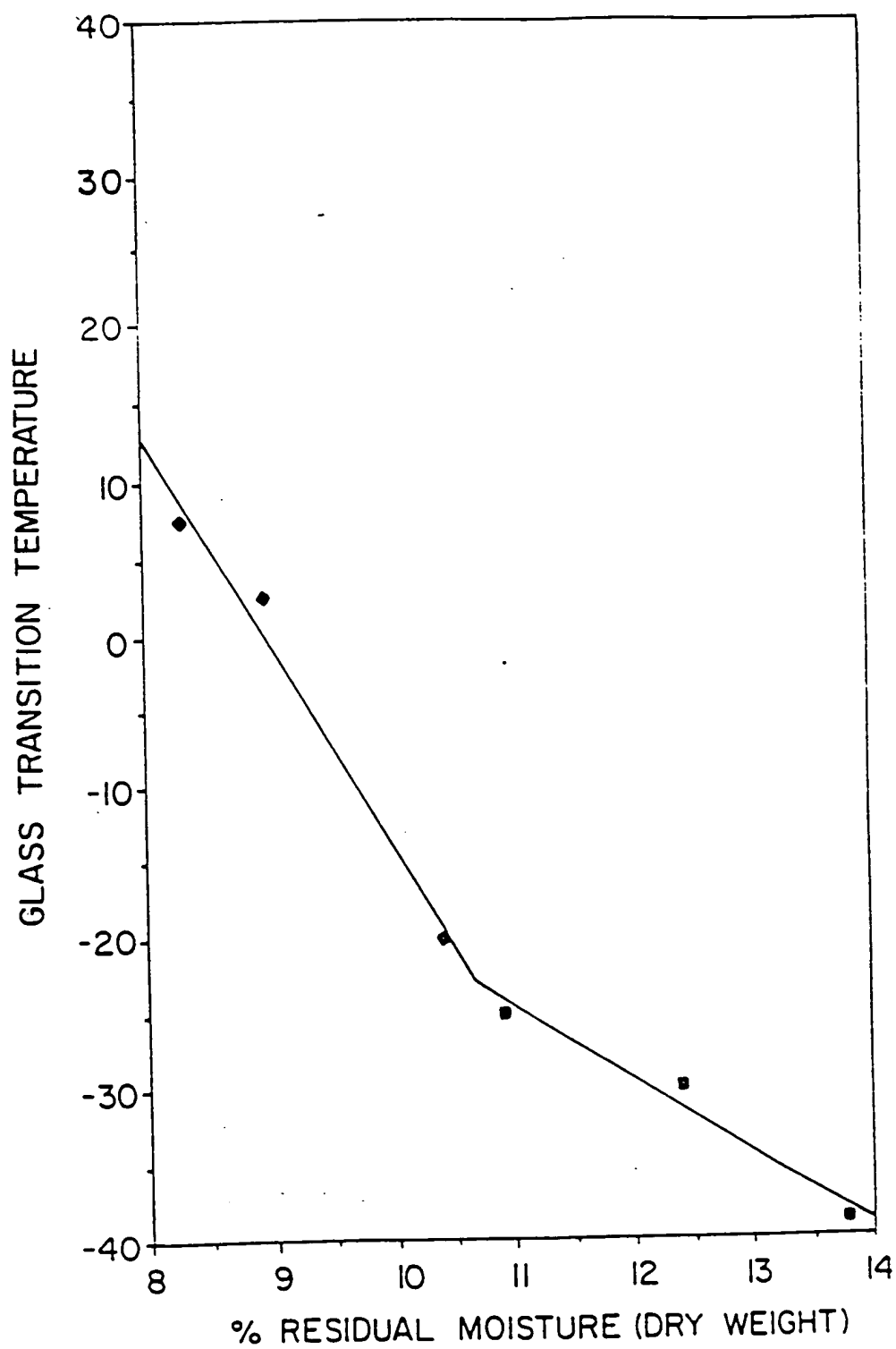


FIG. 3.

*FIG. 4.*

*FIG. 5.*



## INTERNATIONAL SEARCH REPORT

L. national application No.  
PCT/US93/00249

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) : IPC(5): C12N 5/00; A01N 1/02

US CL : 435/1, 2, 240.1; 252/70

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 435/1, 2, 240.1; 252/70

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS, BIOSIS

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X — Y	US, A, 5,045,446 (GOODRICH, Jr. ET AL) 03 SEPTEMBER 1991, SEE ENTIRE DOCUMENT.	1-48 — 49-77



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

16 February 1993

Date of mailing of the international search report

05 MAR 1993

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